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TECHNICAL REPORT
71-45-CE

PROTOTYPE COLD WEATHER FACE MASK

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Samuel Tobey

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Los Angeles, California

Contract No. DAAG17-70-C-0113

February 1971

UNITED STATES ARMY
NATICK LABORATORIES
Natick, Massachusetts 01760

U.S. ARMY MATERIEL COMMAND

Clothing & Personal Life Support Equipment Laboratory
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FOREWORD

Protection of the face under conditions of extreme cold weather is a problem which has been recognized for a number of years. An acceptable device must not only offer thermal protection against wind, cold, blowing snow and frostbite but must be so designed that it will not detract from the individual soldier's combat effectiveness.

This report covers a nine-month system-oriented design study, the objective of which was to develop an improved, lightweight, cost-effective, non-restrictive face mask which would provide protection to the entire face without imposing physiological stress or task performance degradation. The work was conducted by Synsis, Inc., under Contract No. DAAG17-70-C-0113 and directed by Mr. Samuel Tobey.

The contract was initiated under Project No. 1J664713D547-Task 54, Mask Cold Weather (LINCLOE) and was administered under the direction of the Clothing and Equipment Systems Division, Clothing and Personal Life Support Equipment Laboratory of the U.S. Army Natick Laboratories. The Project Officer for the U.S. Army Natick Laboratories was Mrs. Mary E. Darby and the alternate Project Officer was Mr. Herman Madnick.

The U.S. Army Research Institute of Environmental Medicine (ARIEM) a tenant activity at Natick Laboratories, measured the insulation values of various candidate materials. This work was directed by Dr. Ralph Goldman, Director, Military Ergonomics Laboratory at ARIEM. Investigation of low-temperature properties of materials and limited tests using human subjects were conducted at Natick Laboratories under the direction of the Clothing and Personal Life Support Equipment Laboratory and Pioneering Research Laboratory, respectively. Technical personnel at Natick Laboratories also cooperated in specialized phases of this program, namely, Mr. Robert M. White, Research Anthropologist, and Dr. John M. McGinnis, Research Psychologist.

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ABSTRACT

An improved cold weather face mask has been developed which should provide protection from cold, wind, blowing snow, and frostbite in environments to -65°F and 35 mph wind velocities. The mask provides physical compatibility with military clothing and equipment and will not occlude the field of vision. It weighs less than 2½ ounces, covers the forehead, cheeks, nose, ears, chin and mouth, and is designed such that a single-size mask can adequately accommodate the U.S. Army population. Provisions are included to permit eating, smoking, relief of excess moisture accumulations, and elimination of oral and nasal body wastes. The mask is composed of a laminated insulating material facepiece, an oronasal thermal control barrier and an adjustable retention harness. The laminated material consists of a stretch nylon outer layer, a cotton jersey inner layer and an insulating interlayer. In the final configuration, mask models were produced using either a 1/4-inch polyurethane foam or a 3/8-inch polyester felt for the insulating interlayer. The laminated material has sufficient compliance and stretch to conform well to a wide range of facial contours.

The development process involved a nine-month, two-phase, system-oriented design study. The first phase included a design requirements analysis, and a configuration synthesis task. The analyses provided basic thermodynamic, psychophysiological, and compatibility criteria for the selection of candidate materials, configuration concepts, and system designs. The basic design concepts were analyzed and promising candidates selected, fabricated, and subjected to a preliminary evaluation. As a result of the preliminary evaluations, designs for a final prototype mask were selected for further development.

During Phase II certain design modifications, deemed desirable as a result of the preliminary evaluation, were made to the selected design approaches. Quantities of the prototypes were then fabricated and delivered to the U.S. Army Natick Laboratories.

From the preliminary evaluation, it was generally concluded that the area of facial coverage provided by the mask is satisfactory and that the mask, when combined with other elements of Arctic clothing, offers excellent protection against severe windchill.

Although the prototype mask provides acceptable auditory reception severe attenuation was observed when the complete Arctic clothing ensemble is worn. It is thus recommended that techniques to improve audio-transmission through Arctic headwear be developed.

Section I

INTRODUCTION

PROGRAM BACKGROUND

Under certain conditions of temperature and wind velocity, face protection against windchill is necessary to prevent frostbite and to maintain operational proficiency. Such protection, however, must be compatible with military equipment and clothing and should not degrade an individual soldier's task performance. Field reports indicate that the present standard cold weather mask has certain deficiencies which make it unsatisfactory to the user. These include poor low temperature characteristics (vinyl stiffens and may crack at -65°F), poor fit among the cross-section of U.S. Army population, interference with vision among some personnel, lack of stability in a dynamic environment, and poor compatibility with goggles and glasses.

Over the past several years, various types of experimental cold weather face masks were developed in an attempt to improve the design and construction of the mask. However, none of these experimental models were completely acceptable. In 1964, for example, a commercial face mask made of non-woven fabric and designed to cover only the nose and mouth was investigated and tested during the 1964-65 winter in Alaska (1). A mask under development by Canada was also tested in Alaska at about the same time by the Combat Development Command (2). The various experimental masks showed certain improvements over the standard mask but each introduced deficiencies of its own. The non-woven mask provided poor area coverage and stability. The Canadian mask had no provision for oronasal access, and fit poorly among some elements of the U.S. Army population. It was therefore deemed advisable to establish a program to develop a new mask which could incorporate the more desirable features of each of the experimental masks.

OBJECTIVE

The objective of this program was to develop an improved, lightweight, cost-effective mask which could provide the U.S. Army population with cold weather protection for the entire face with no physiological or task performance degradation.

SYSTEM DEVELOPMENT PROCESS

A two-phase system engineering approach, consisting of a series of inter-related tasks as shown in Figure 1, was adopted for this study. Phase I consisted of a requirements analysis, concept synthesis, and a prototype design and evaluation. Phase II involved the detail design and fabrication of the selected prototype.

The study started with a generalized system analysis directed at operationally defining the system thermodynamic, anthropometric, psychophysiological and compatibility requirements and constraints. With these data as basic criteria, a concept synthesis task was initiated and candidate mater-

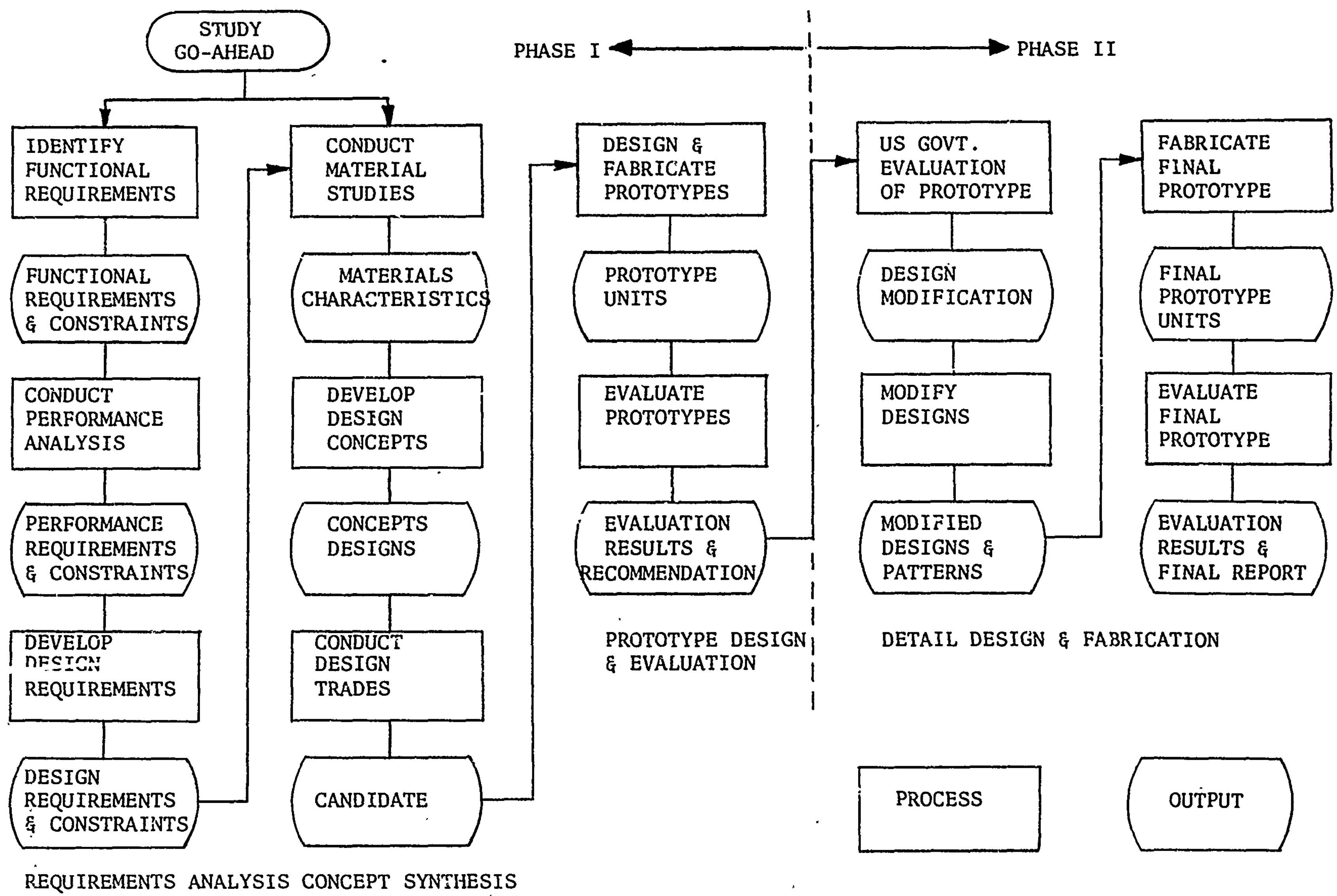


Figure 1. System Development Process

ials and configurations selected. The candidate materials and configurations were then combined into a series of conceptual system designs and theoretically evaluated. Prototypes of the more promising concepts were fabricated and subjected to preliminary evaluation tests. Based on the results of these tests, certain design modifications were incorporated and quantities of two selected prototypes fabricated and delivered to the U.S. Army Natick Laboratories.

The final prototype mask design is defined in Section II of this report. Sections III through VI describe the system engineering process utilized to develop the mask design. Conclusions and recommendations derived during the program are presented in Section VII.

Section II

FINAL PROTOTYPE MASKS

DESIGN DESCRIPTION

The cold weather face mask developed under this program is shown in Figures 2 through 6. The prototype is a one-piece, close fitting mask in a single size which is adjustable to fit the range of head and face dimensions typical of the U.S. Army male population. It incorporates a commercially available temperature-control oronasal barrier to prevent the inhalation of extremely low temperature ambient air, an insulating facepiece which covers the forehead, cheeks, nose, ears and chin, and a retention harness (Figure 3). The mask is designed to be compatible with and to supplement existing U.S. Army cold-weather protective equipment and to be compatible with other equipment associated with military operations in a cold environment.

The prototype facepieces were constructed of laminates of insulating material sandwiched between stretch nylon on the outer surface and cotton jersey on the inner surface. Half the prototypes incorporated 1/4 inch thick open-cell polyurethane foam as the insulating layer while the other half used 3/8 inch thick polyester felt. Both types of laminates have sufficient stretch to permit the masks to conform well to a wide range of facial contours.

All edges of the mask facepieces were bound using an overlock safety stitch (Seam Type SSa-2 and Stitch Type 516 of Federal Standard 751a (3). The seams were joined using a standard zig-zag stitch, and then bar-tacked to prevent unraveling or fraying. All sewing was accomplished with a polyester/cotton wrapped thread, conforming to Specification MIL-T-43548 (4).

As illustrated in Figure 4, a single visual port is used. This provides less visual restriction than two separate eyeports and does not significantly reduce the protection afforded. A 1/4 inch wide, 1-1/4 inch long elastic strap connecting the upper and lower edges of the visual port is utilized to aid in keeping eyeglasses in place and to preserve the dimensional opening of the port.

The oronasal port and barrier are illustrated in Figures 3 and 4. The oronasal barrier is used to cover the port and to raise the inhaled air temperature above ambient. The barrier is adapted from a commercially available item originally developed to provide the temperature control function. The oronasal barrier is permanently attached to the facepiece when wearing a non-elastic nylon strap on one side. On the other side, a cotton tab is sewn onto the barrier to allow easy removal or attachment to the facepiece with cold weather handgear. Hook and pile fastener tape provides the actual attachment of the oronasal barrier to the facepiece. A 1/4 inch wide strip of pile is attached to the inside upper three-quarters of the oronasal barrier's circumference, and one-inch wide strips of hook are sewn onto the cold weather facepiece around the oronasal port. This arrangement is illustrated in Figure 4.

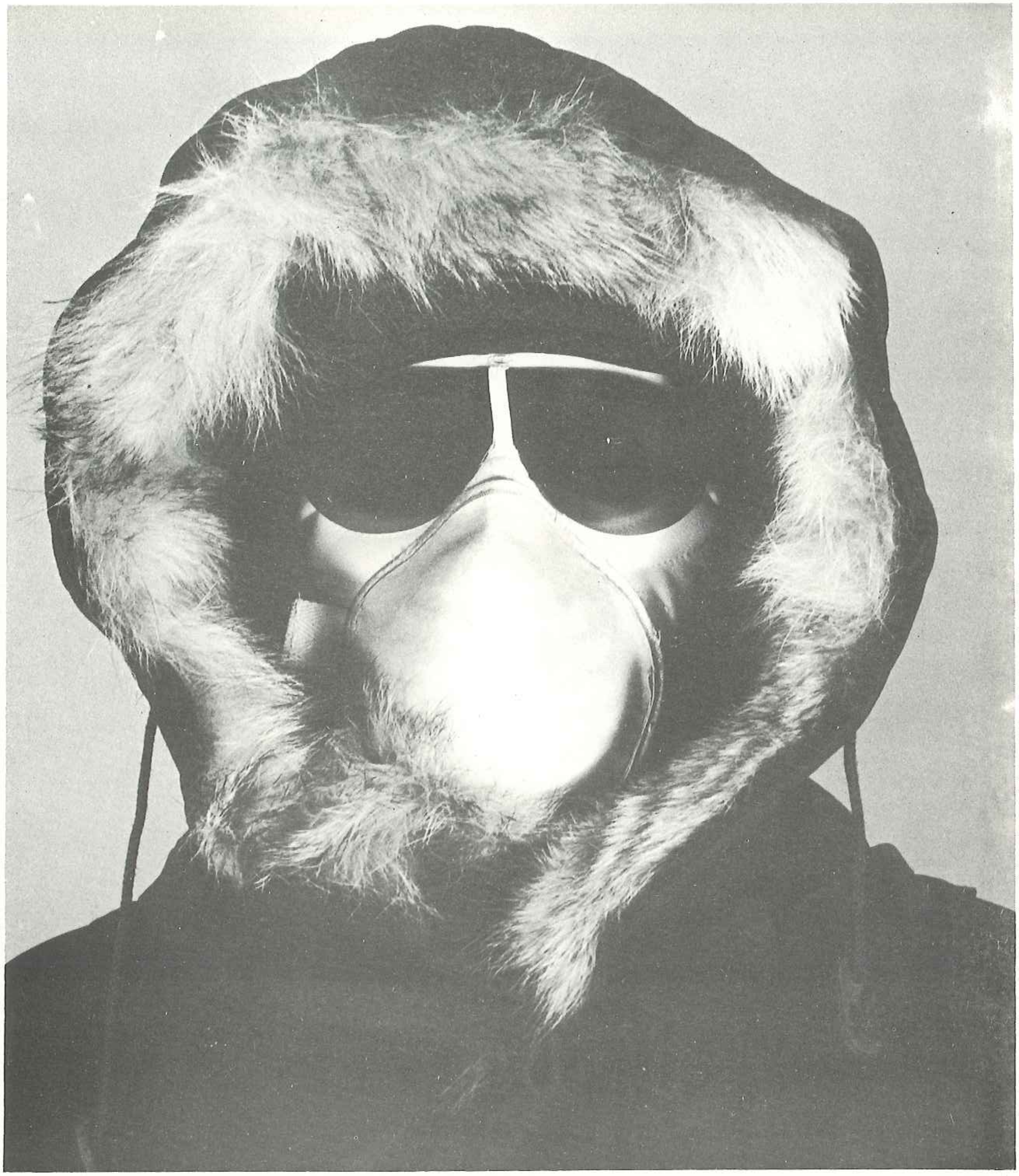


Figure 2. Prototype Cold Weather Mask Worn with the Standard Arctic Protective Headgear Assembly and Glasses

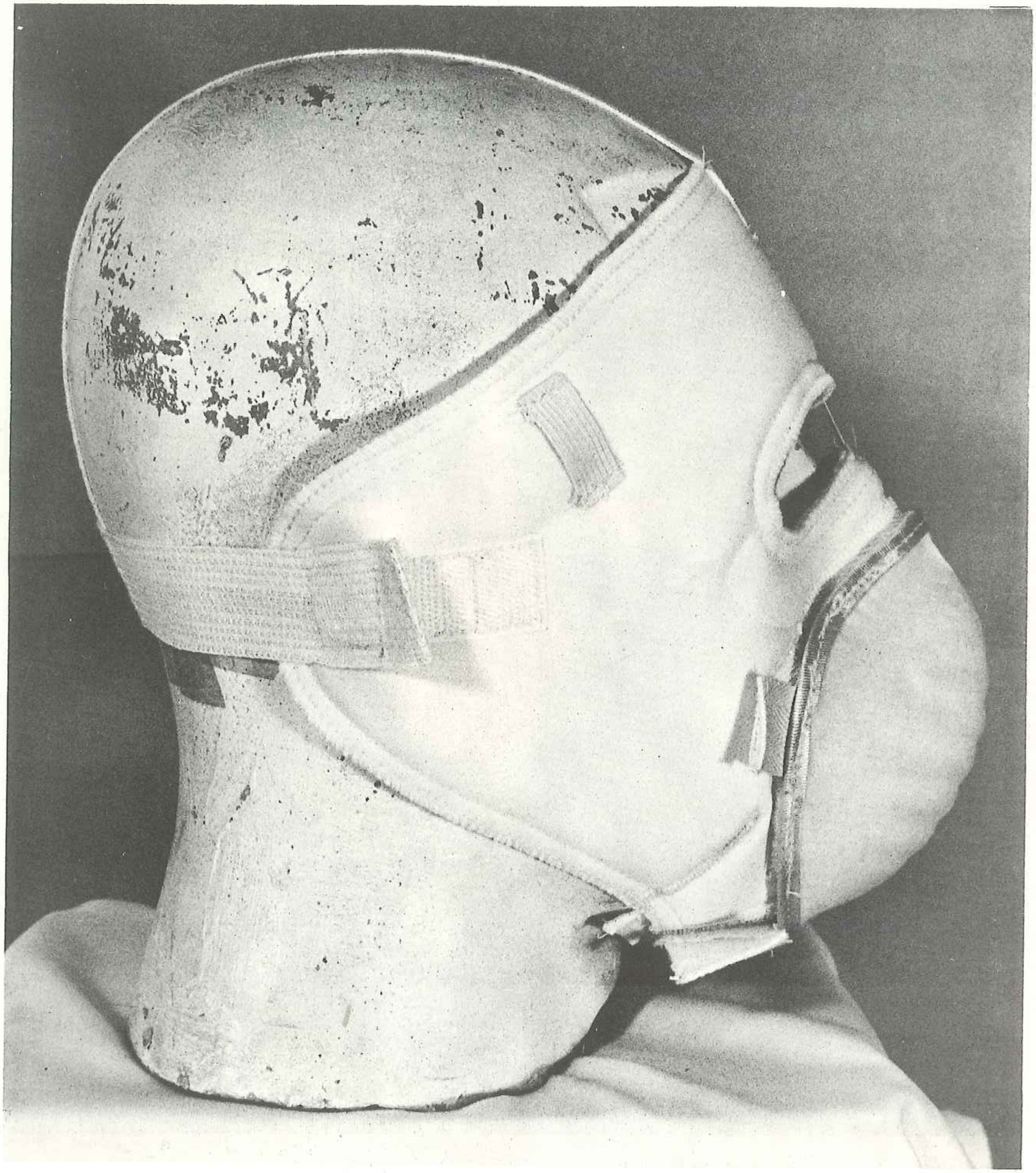


Figure 3. Side View of Cold Weather Mask
Showing Elastic Eyeglass Holder Loops

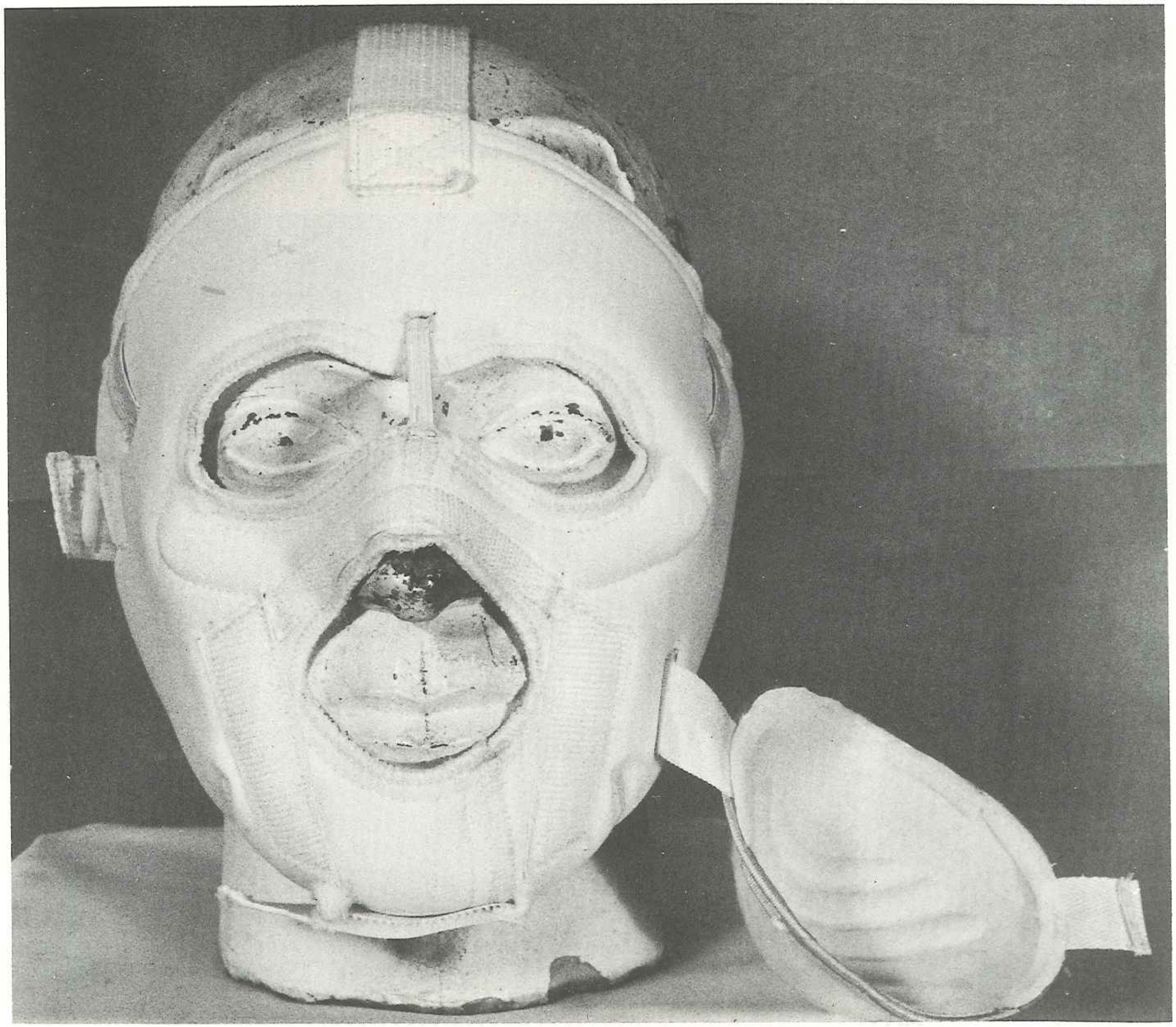


Figure 4. Front View of Cold Weather Mask Showing Single Visual Port and Oronasal Barrier in the Open Position

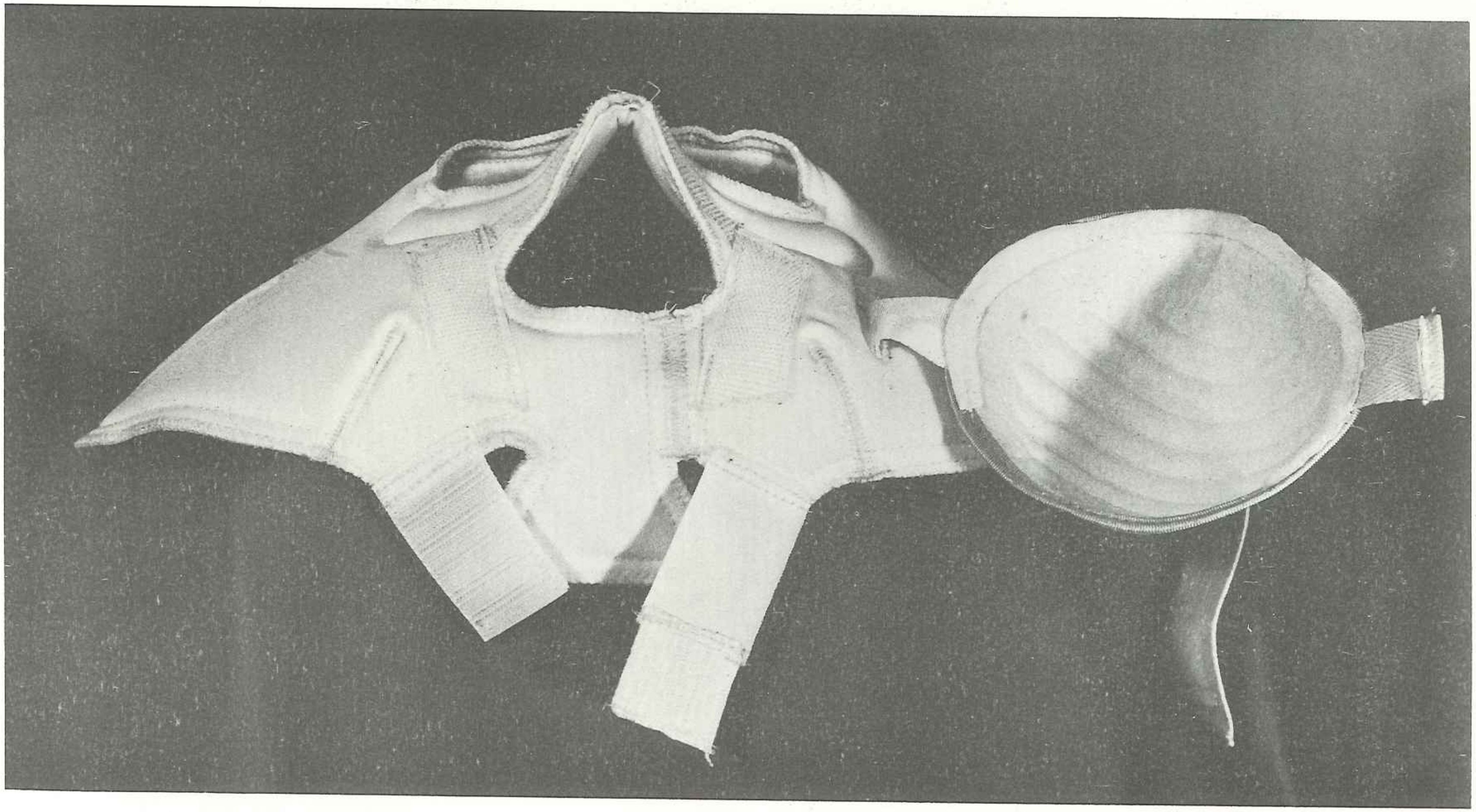


Figure 5. Chin Pocket Adjustment for Face Length Adaptation

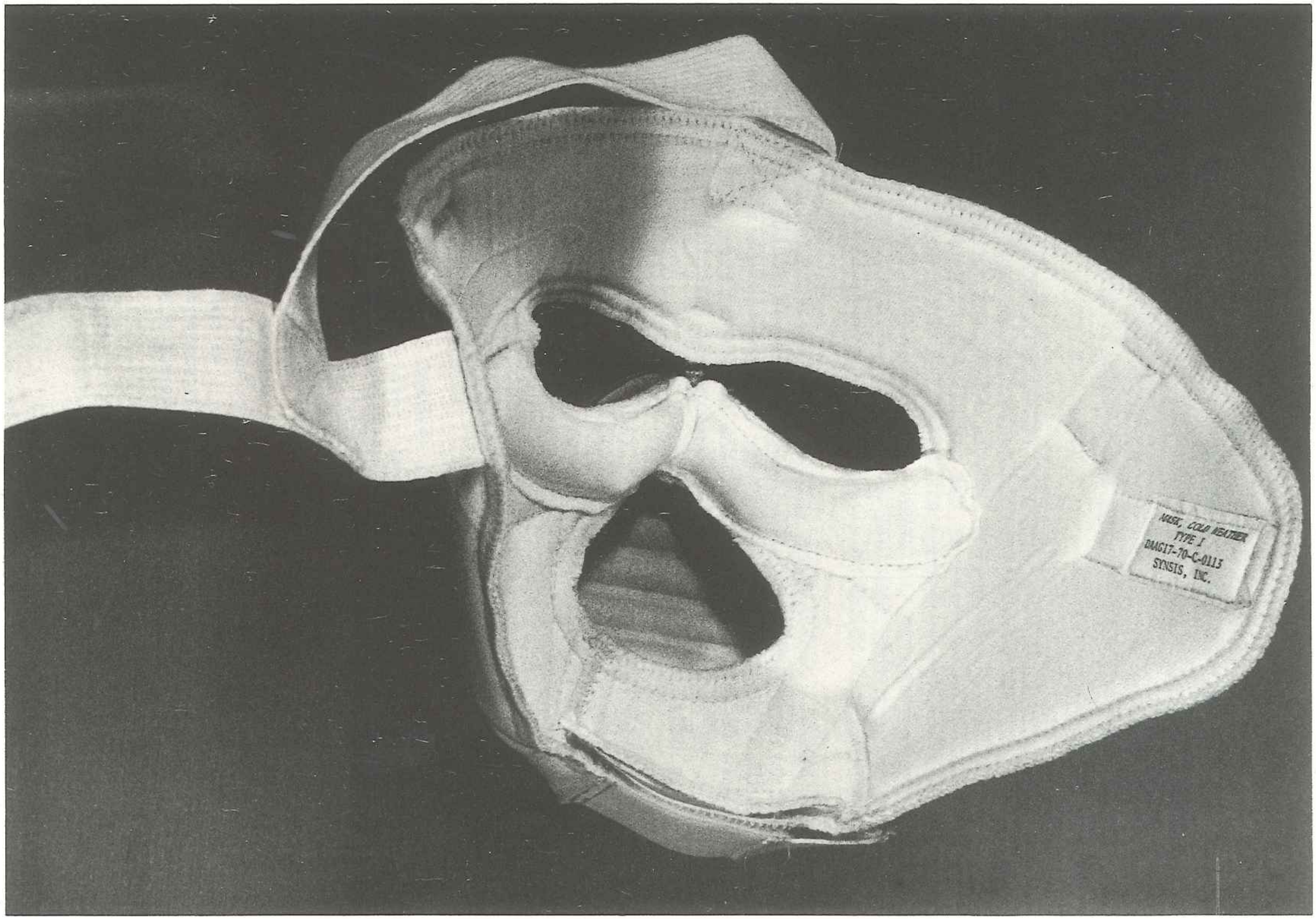


Figure 6. Internal View of Cold Weather Mask Showing Retention Harness and Stiffener Bar/Padding Combination

Adjustment is provided to make the mask compatible with a wide range of head and face sizes. Underchin adjustment straps are used to compensate for different face lengths. The straps consist of two 1-1/2 inch wide, 2-1/4 inch long strips of hook and pile tape arranged as shown in Figure 5. A tab is attached to the pile strap to allow easier adjustment. Size variation is accomplished by varying the length of overlap between the hook and pile tape.

Adjustments for head circumference variations are incorporated into the head harness. The harness consists of a single overhead strap sewn to the upper edge of the facepiece (Figure 4) and to the center of a single back strap (Figure 6). One end of the back strap is sewn to the edge of the face piece at one side (Figure 6), while the other end attaches through a hook and pile fastener to the other end (Figure 3). Back strap length is adjustable through this hook and pile fastener. The straps are constructed of cotton elastic webbing to allow for jaw movements.

Figure 6 shows a combination stiffener bar/padding which is installed on the inside of the mask along the bridge of the nose and extending under the visual port. The malleable stiffener bar permits the mask to be molded with the fingers to fit snugly against the nose and face. The padding helps prevent moist, warm exhaled air from penetrating into the visual port and causing fogging of glasses or goggles.

Eyeglass holder loops are shown in Figure 3. These are provided to hold eyeglass stems. Alternately, buttonhole-type slits are provided to allow eyeglass stems to rest upon the wearer's ears. The center of the eyeglass frames can be held in place on the bridge of the nose by slipping the glasses under the elastic visual port elastic strap (Figure 2).

PERFORMANCE CHARACTERISTICS

The prototype mask provides better thermal protection, is lighter, and results in better military equipment and clothing compatibility than the current standard mask. Based on the analysis and limited testing conducted during this program, it also appears to comply with the physical and performance requirements specified in the contract and/or established during the contract.

Table I compares the physical and performance requirements with the characteristics of the final prototype mask. In some cases where specific data could not be established, estimates are presented. In some areas where the results are subjective, relative comparisons with the current standard mask are included.

TABLE I

CHARACTERISTICS OF THE FINAL PROTOTYPE MASK

REQUIREMENT	PROTOTYPE SYSTEM CHARACTERISTIC
PROTECTION	
Shall protect against frostbite and cold discomfort in environments to -65°F and 35 mph winds.	System insulation factor designed to maintain skin temperatures above 60°F in environments of -65°F and 35 mph winds for all areas of face covered by the mask.
Shall protect all portions of the face not encompassed by the insulating cap of the Arctic protective headgear assembly.	Mask covers the forehead, cheeks, nose, mouth, chin and ears and includes a minimum of one-inch overlap with the insulating cap to prevent leakage at the interface.
Shall protect against the inhalation of air at environmental temperatures which will tend to cause frostbite in the nostril area.	Oronasal barrier provides a thermal exchange dead space which ensures inhalation temperatures sufficiently higher than the -65°F environment to prevent frostbite in the nostril/mouth respiratory tract.
WEIGHT AND BULK	
Shall not weigh more than 4 ounces.	Weight 2-1/2 ounces.
Shall be compactable to permit the user to store mask in a pocket or the load carrying pack.	Can be folded compactly in a flat package which will fit into a pocket with negligible bulging
Shall not increase bulk on head such that it will interfere with the use of other protective clothing or equipment or with the performance of tasks requiring proximity of equipment.	Does not interfere with the use of protective clothing headgear, optical equipment, weapons, or communication equipment any more than does the current mask.

TABLE I (continued)

CHARACTERISTICS OF THE FINAL PROTOTYPE MASK

REQUIREMENT	PROTOTYPE SYSTEM CHARACTERISTIC
SIZING AND FIT	
Shall accommodate the user population with no greater than three sizes.	A single-size mask will accommodate the user population.
Shall fit the wearers face snugly without the incidence of pressure points or discomfort.	Mask is individually adjustable to provide a snug fit. Adjustment tabs will ensure individual comfort. Local pressure points or discomfort are an indication of improper donning or adjustment.
Shall not move on the face during head and jaw movements, during the performance of gross body movements, or when in contact with other protective headgear.	Snug fit and facial contour indexing maintain the mask in position and stable under typical dynamic head and body movements. There are no mask components which can snag on other elements of the protective headgear assembly.
ENVIRONMENTAL COMPATIBILITY	
Shall not stiffen or resist flexure when exposed to -65°F during wear or after storage at -65°F.	Mask materials will not stiffen, crack, become damaged or become otherwise unserviceable during wear or after storage at -65°F.
Shall not suffer damage due to ice formation during wear and shall be capable of having ice removed during wear.	Frost and ice are easily removed because of surface texture and stretch characteristics of the mask. Removal can be accomplished while wearing gloves or mittens.

TABLE I (continued)

CHARACTERISTICS OF THE FINAL PROTOTYPE MASK

REQUIREMENT	PROTOTYPE SYSTEM CHARACTERISTIC
DONNING/DOFFING	
Shall permit ease of donning and doffing.	Mask is donned without assistance. Shape of facepiece prevents improper donning.
Shall be donned when wearing gloves and/or mittens.	Donning and adjustment can be performed when wearing gloves and/or mittens.
CLOTHING AND EQUIPMENT COMPATIBILITY	
Shall be capable of being worn with cold weather headgear, with or without goggles.	Can be worn with cold weather headgear, with or without goggles or sunglasses.
Shall be compatible with the use of any military weapons or equipment and shall not restrict the ability of the individual to operate these any more than the current mask.	Compatible with, and does not restrict the use of, military weapons or equipment any more than the current mask.
Shall provide a means to accommodate the use of corrective eyeglasses.	Provides method for retention and positioning corrective eyeglasses.
TASK COMPATIBILITY	
Shall not unduly restrict free head movement, breathing, hearing, talking, smelling or field of vision.	Does not restrict free head movement or field of vision any more than the current mask. Does not unduly restrict breathing, hearing, talking or smelling. Hearing may be restricted with complete Arctic headgear ensemble; parka, cap, mask.

TABLE I (continued)

CHARACTERISTICS OF THE FINAL PROTOTYPE MASK

REQUIREMENT	PROTOTYPE SYSTEM CHARACTERISTIC
ACCESS	
Shall be provided with a means to aid in pulling away or lifting the nose and mouth section for blowing the nose, spitting, eating, etc. and to relieve excess moisture accumulation.	Removable oronasal barrier provides required access.
Mask closures, where provided, shall be easy to open and close while wearing cold weather handwear.	Oronasal barrier is easy to open and close with cold weather handwear by use of a single tab and hook and pile fastener.
ELECTROSTATIC POTENTIAL	
Materials shall not develop an electrostatic potential greater than the materials used in the standard cold weather ensemble.	Mask materials identical to those used elsewhere in cold weather ensemble.
COLOR	
Shall be white in color in accordance with existing camouflage policy for snow covered areas.	White in color but can be made in other colors if desired.
STYLE	
Configuration and construction of the mask shall inspire acceptance and confidence during use.	Limited tests evidenced good wearer acceptability

TABLE I (concluded)

CHARACTERISTICS OF THE FINAL PROTOTYPE MASK

REQUIREMENT	PROTOTYPE SYSTEM CHARACTERISTIC
COST	
Final design shall be compatible with large quantity production at low cost.	Cost of mask in large production quantities is estimated to be economically feasible.
LAUNDERABILITY	
Shall permit washing by the individual under field conditions without affecting its environmental protective characteristics.	Mask can be hand washed without loss of protective characteristics, but oronasal barrier may lose body, shape and protective characteristics after multiple washings.

Section III

REQUIREMENTS

A system oriented analysis was conducted to define the performance and design requirements for the cold weather face mask. These requirements were based on the functional requirement of providing protection to the individual soldier in extreme windchill environments, and the functional constraint of compatibility with personal and military equipment and operations.

The analysis was initiated by first identifying the critical requirements and then, through iteration with the system synthesis task, establishing values or design criteria for these parameters. Figure 7 identifies the requirements which were considered during the analysis.

THERMAL

A thermal analysis was conducted which considered all of the potential modes of heat transfer from facial surfaces covered by various types of thermal protective layers. The analysis demonstrated the validity of considering only the "worst case" condition of a -65° environmental temperature with a 35 mph wind. The preliminary study also demonstrated that radiative losses would be insignificant compared with convective losses.

Data obtained from the literature indicates that the threshold for skin damage due to low temperatures is at 60 to 65°F (5). Other sources also suggest that insensible perspiration rates for facial skin temperatures below 90°F are approximately 3 grams/hr/ft^2 (6, 7, 8, 9). The maximum resulting evaporative heat loss is about 7 Btu/hr ft^2. It is assumed that the evaporated moisture is transferred directly to ambient rather than condensing within the mask and contributing to the quantity of heat which is lost to ambient from the external surface of the mask.

A simplified thermal model based on the results of the analysis and literature survey expresses skin surface temperature as a function of environmental temperature, Te, and the total "thermal resistance" R, between the skin and the environment. The physical arrangement is depicted in Figure 8. The "resistance" is made up of the resistances of an air gap between the face and the mask inner surface, the mask itself, and the thermal boundary layer at the mask exterior as shown below:

$$R = x_a/k_a + x_m/k_m + 1/h_c$$

where x's are thickness dimensions
k's are thermal conductivities
h_c is external film coefficient and subscripts a and m refer to the face-to-mask airgap and the mask material, respectively.

Figure 9 shows skin temperature, Ts, versus Te and R for an assumed value of head conductance, C = 2.35 Btu/hr ft^2 °F (10), and head core temperature, T_c = 98.6 °F. R is presented as a function of external film coefficient, h_c, and mask conductance, k_m/x_m, in Figure 10. The Figure is drawn for an airgap thickness, x_a, equal to zero.

According to the criterion of minimum skin temperatures in the 60°

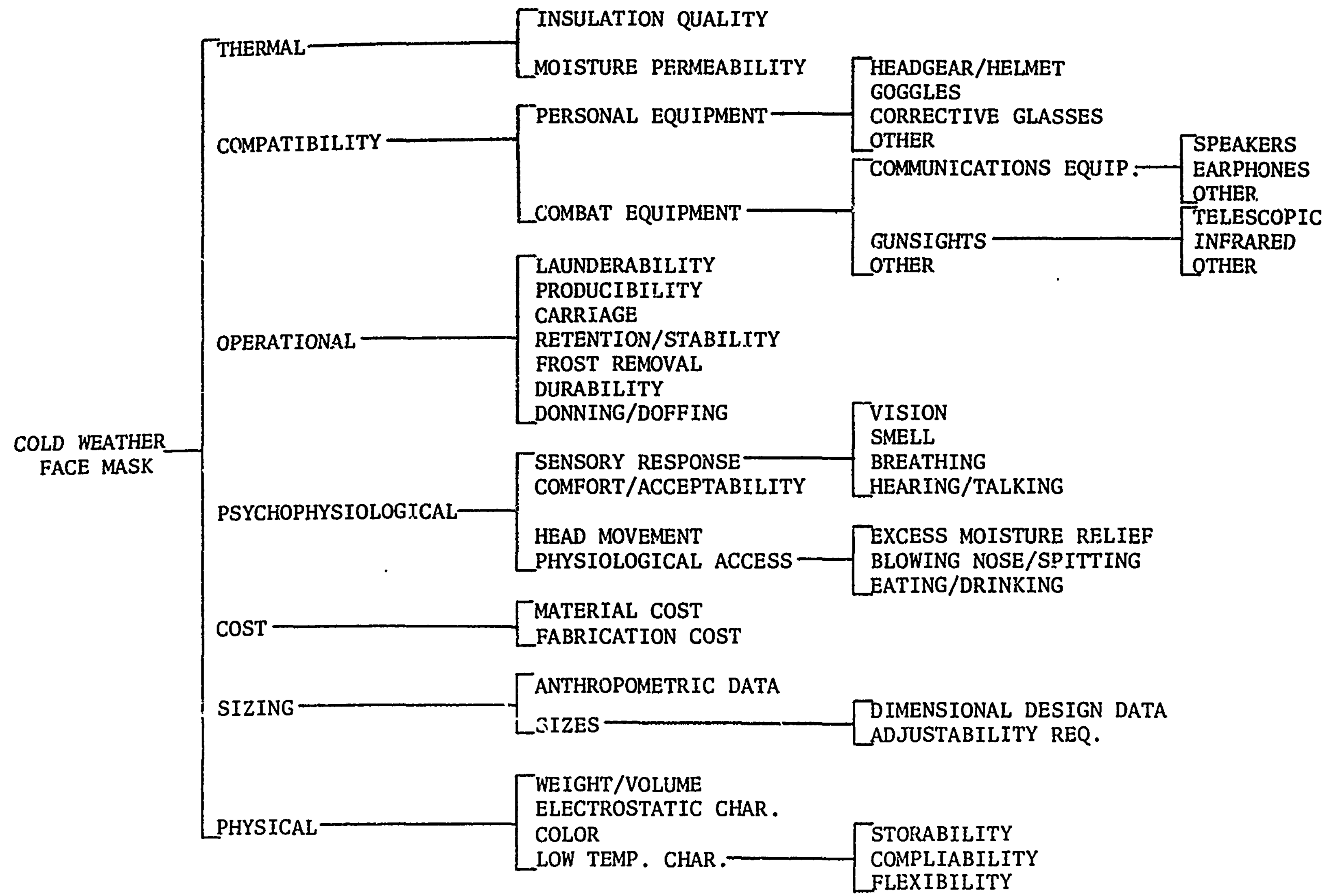
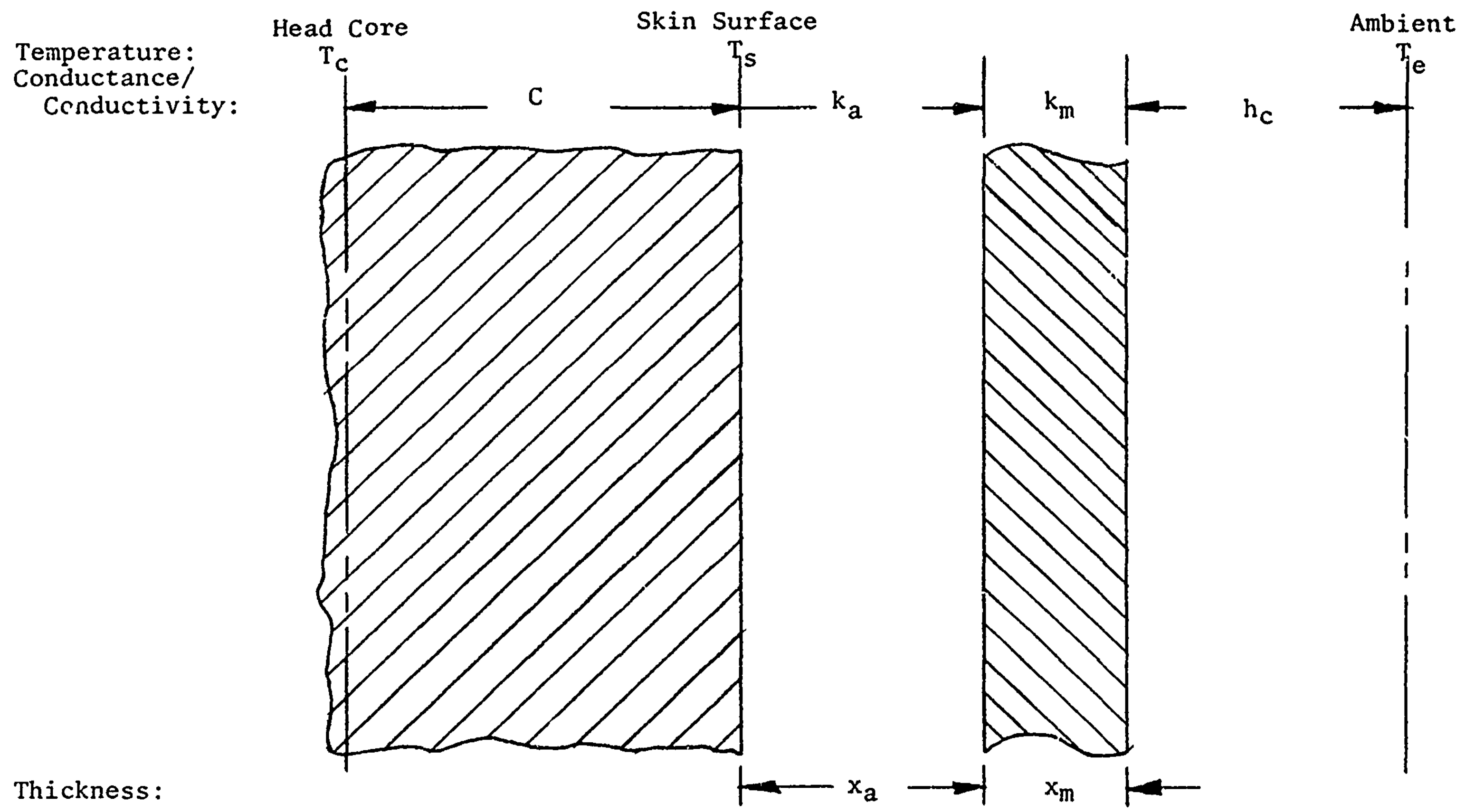


Figure 7. Design Requirements



$$q/A = C(T_c - T_s) = (1/R)\ (T_s - T_e) + q_{evap}$$

$$R = x_a/k_a + x_m/k_m + 1/h_c$$

Figure 8. Physical Arrangement of Thermal Analysis Model

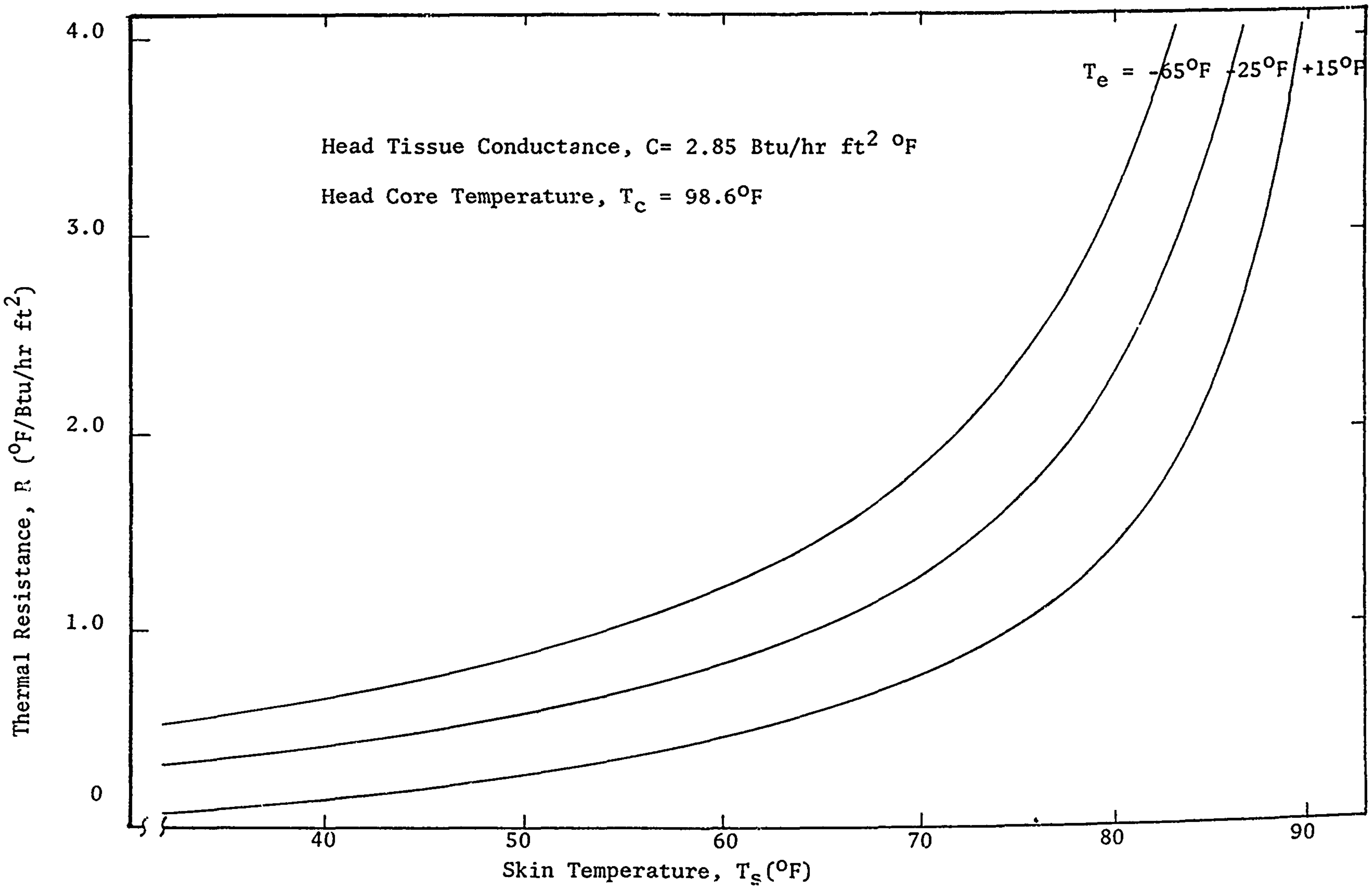


Figure 9. Required Thermal Resistance as Function of Skin Temperature and Environmental Temperature

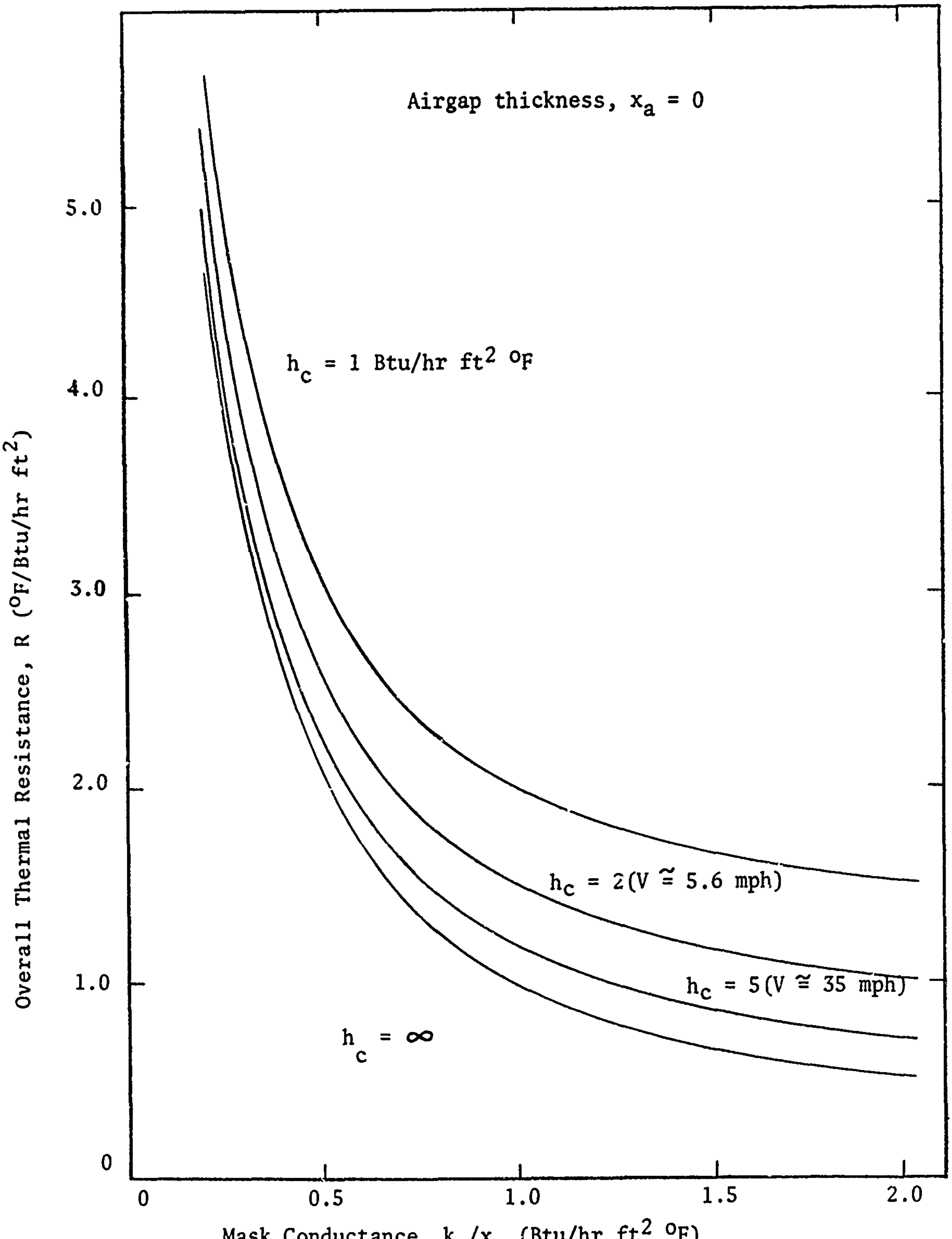


Figure 10. Effects of Mask Conductance and External Film Coefficient on Overall Thermal Resistance

to 65°F range, the minimum value for R should be between 1.2 and 1.5 (see Figure 9). An R of 1.2 requires a k_m/x_m, of not more than 1.0 when the external film coefficient is in the order of 5 Btu/ hr ft^2 °F (corresponds to a wind speed of 35 mph).

For materials investigated in the materials study task, the value of k_m is typically about 0.25 Btu in/ hr ft^2 °F. Minimum thickness for these materials would, therefore, be about 0.25 inch. If materials with lower conductivities were used or if the performance criteria were altered to permit lower skin temperatures, the material thickness could be reduced.

In actuality, the above analysis is conservative; some airgap will exist between the mask and the face. Since the conductivity of air is roughly half (0.13 Btu in/hr ft^2 °F) that of the insulating materials studies, a small airgap will contribute significantly to, R, the thermal resistance of the protective mask.

The effect of material thermal characteristics on "feel" and mask comfort were investigated analytically. It was determined, for example, that materials with low "thermal inertia" (kpc) (k = conductivity, p = density, c = specific heat), would probably cause less discomfort to the mask user who donned a mask, cold-soaked at -65°F, than would those with greater values of kpc. This hypothesis was verified by means of simple tests in which numerous material samples were chilled to -65°F and then quickly placed against the face.

Vapor permeability of materials was investigated to determine its effect on protection capability. Because of the low rate at which insensible perspiration is generated and evaporated, the amount of heat loss due to evaporative cooling is extremely small (less than 10% of the total heat loss rate), and the skin temperature can only be raised by 1° - 2°F in a -65°F environment by eliminating evaporative transfer. On the other hand, there appear to be significant disadvantages to preventing vapor loss. Sweat continues to be generated even though it is prevented from evaporating and will accumulate as a liquid within a vapor-impermeable mask.

Analysis indicates that if the mask is made sufficiently permeable to water vapor, condensation within the mask will not occur under dynamic equilibrium conditions. A minute quantity of moisture may condense within such a mask when it is donned in the cold but it should reevaporate when equilibrium is reached. Only when active sweating occurs is there likely to be any appreciable amount of liquid water in a permeable mask. Moisture may collect if exhaled air passes through the permeable material.

The effect of respiration on heat loss was also investigated. The analysis showed that the tissues at the entrance to the respiratory tract (nostrils, or lips) can be cooled to the freezing point by inhalation of air at -65°F. The result is consistent with the experience of Synsis personnel who have conducted experiments in -65°F environments (11). The problem results from the relatively high convective transfer coefficient for air entering the nostrils or passing between the lips. Since the film coefficient cannot be lowered appreciably, it is necessary to raise the inhaled air temperature if frostbite is to be avoided. The use of an oronasal temperature

control mask appears to be an adequate solution to this problem.

A persistent problem associated with cold protection is the loss of vision due to fogging or frosting of goggles or corrective lenses. This occurs when the surfaces of such optical equipment come in contact with air having a dew-point temperature higher than the lens or goggle surface. Solutions to the problem involve either 1) control of the optical element temperature to maintain it at a value which is always greater than the dew point of surrounding air, or 2) restricting the dew point of contacting air to low values. In this program only the second course was open since the procedures and equipment for controlling lens temperatures were beyond the program scope.

The major source of water vapor which may condense on cold optical element surfaces is exhaled air. Inspection of existing cold protective masks reveals that gaps and channels exist between the masks and the wearer's face at either side of the nose. These channels permit exhaled air to flow upward, into the interior of the protective goggles. The standard goggles are not able to dissipate the moisture laden air quickly enough to prevent fogging. A solution to the problem was to incorporate an effective seal around the eye openings in the mask to prevent exhaled air leakage into the goggle or corrective lens area.

COMPATIBILITY

In order to comply with the functional constraint of equipment and operational compatibility, the cold weather face mask can not interfere with the use of weapons or equipment any more than the current field mask. Nor can it interfere with the protection offered by other personal equipment. It therefore must be physically and operationally compatible with optical/sighting equipment, weapons/equipment use, and personal clothing. Table II summarizes the requirements for equipment compatibility.

OPTICAL

If protection and operational proficiency are to be maintained, provisions must be made in the face mask for accommodating and securing corrective eyeglasses, sunglasses, and cold weather goggles such that their function is not degraded. This will include maintaining approximately the same lens-to-pupil distance as that which exists without the face mask. The mask shall also not induce fogging of the glasses or goggles any more than the current field mask.

The accurate and rapid use of optical sighting or viewing equipment such as gun-sights, binoculars, and I.R. devices, require close pupil-to-lens (or sight) distance. The cold weather goggles are currently a major constraint in the use of these items, but they can be rapidly removed or lowered from the eyes. Therefore, the mask shall not interfere with rapid removal or lowering of the goggles and shall not increase the pupil-to-lens distance any more than the standard mask without goggles.

PROTECTIVE CLOTHING/EQUIPMENT

The protection offered by items of personal clothing and equipment can

TABLE II

EQUIPMENT INTERFACE COMPATIBILITY

EQUIPMENT TYPE	INTERFACE IDENTIFICATION	POTENTIAL DESIGN PROBLEMS
THERMAL PROTECTIVE CLOTHING		
Insulating Cap	Cap encloses all portions of head and neck except for face and forehead.	Protective mask must integrate with insulating cap such that continuous thermal protection is achieved and that cold air cannot leak at the interface; protective mask shall not cause any degradation of insulating cap performance.
Winter Hood with Fur Ruff	Encloses head; fur ruff can be used to enclose face; fur ruff interferes with vision and may induce a moist air dead-space under some conditions of wear (moist air tends to fog lenses).	Combination of mask with hood shall not increase lens fogging potential; electrostatic potential shall not develop between ruff and mask such that fur clings to the mask preventing or limiting vision; ice formation on mask shall not result in adhesion of ruff to mask.
Mittens and Gloves	Protective handgear limits manual (finger) dexterity required for manipulation of the protective mask.	Protective mask shall be suitable for donning without assistance when wearing protective handgear; readjustment of mask shall be possible without removing gloves; oronasal access is to be opened and closed when wearing gloves; adhesion of gloves to moist mask surfaces shall not occur due to icing.

TABLE II (continued)

EQUIPMENT INTERFACE COMPATIBILITY

EQUIPMENT TYPE	INTERFACE IDENTIFICATION	POTENTIAL DESIGN PROBLEMS
OPTICAL		
Corrective Eyeglasses	Normally supported by bridge of nose and ears; visual field correction depend on limiting clear-eye distance.	Loss of support element availability; improper alignment between corrective lens and eye; induction of lens fogging due to moist expired air; potential frosting of lens due to loss of heat flow from face to lens surface.
Cold Weather Goggles	Goggles are designed with a sealing periphery adaptable to facial contours; protective performance depends on preventing the rapid flow of cold air; have a restraint strap which encircles the head.	Design protective facepiece with sufficient compliance to preserve seal with goggles; prevent exhaled air from impinging on lens surfaces and causing fogging and/or frosting; noninterference with donning and retaining goggles.
Optical Sights	Optical sighting equipment is designed for use without facial and eye encumbrances (ie. are designed to be used close to face and eyes).	Minimize bulk in head and eye areas which prevent sighting devices from being used within the sight design clear-eye distances; compression of protective mask components must not result in degraded performance or induction of pressure points which may result in frostbite.

TABLE II (concluded)

EQUIPMENT INTERFACE COMPATIBILITY

EQUIPMENT TYPE	INTERFACE IDENTIFICATION	POTENTIAL DESIGN PROBLEMS
HELMETS	Helmets are designed so that the retention and suspension system contacts the head; retention strap used to maintain helmet on head.	Bulk of protective mask is not to displace helmet from stable wear position; underchin retention strap shall be functional when wearing mask; removal of helmet shall not require protective mask removal.
	Some helmets are equipped with communications headsets.	Mask shall not prevent use of helmet headset.
COMMUNICATIONS	Microphones and headsets are designed for use close to or touching the body (lips and ears). Integrated handpieces are designed to service the mouth and ears simultaneously and have not been designed to compensate for bulk encumbrances on the face.	Mask is to be designed with low bulk to ensure compatibility with communications handsets; mask shall not distort either oral or aural sounds such that communications intelligibility is degraded.
WEAPONS	Weapons designed for use in proximity to the head are degraded in performance when displaced by bulk mounted on the face and head; olfactory cues are important in assessing continued optimun performance of some weapons.	Mask is to be designed to permit normal use of weapons without displacement of weapon; mask is to prevent excessive rate of thermal loss to cold-soaked weapon; freezing at contact point with weapon is not to occur or ice formation is to be broken without damage to mask.

not be degraded as a result of wearing the face mask. Nor can the comfort and stability of these items be impeded. The mask must therefore be compatible with the helmet and thermal protective clothing around the head area.

Cold weather handwear is usually worn in severe windchill environments. Thus, donning, doffing and manipulation of the mask and its components shall be accomplished while wearing cold weather handwear.

WEAPONS/EQUIPMENT

To maintain operational proficiency the mask can not interfere with the wearers performance in the use of weapons or communications equipment any more than the standard mask. Therefore, it must be compatible with weapons operation, microphones, headsets or any other elements of a communication system.

OPERATIONAL

Any item of personal protective equipment must be compatible with certain elements of the military environment. Those elements with which the face mask must be compatible are identified in Figure 7. Requirements for these elements or parameters are presented in Table III, together with remarks as to the rationale for establishing the requirement.

PSYCHOPHYSIOLOGICAL

The cold weather mask will be worn for various durations of time ranging to a maximum of approximately 8 hours. Throughout this wear period the mask is intended to permit the individual to perform both routine and unusual activities within the extremely cold environment. Consequently, the objective of any mask design is to ensure that wearer performance is maintained at a level equivalent with unmasked performance and that the mask does not impose new constraints. Table IV summarizes the psychophysiological requirements which, in general, are intended to ensure wearer performance equivalent to the unmasked condition.

COST

Because of personnel acceptance criteria, the cold weather mask should be an item of single issue equipment. Generally, personnel will reject a face mask which has been used by other personnel for perceived hygienic reasons even though adequate launderability is assured. Consequently, the mask is assumed to have a relatively short utilization life and a high replacement rate.

While this criteria suggests a throwaway, single-use mask the problems of logistics and durability requirements during wear tend to make this approach overly expensive. The mask should therefore be a reusable mask which can be produced at very low cost.

SIZING

The cold weather mask is required to accommodate all U.S. Army field

TABLE III

OPERATIONAL REQUIREMENTS

DESIGN CRITERIA	REQUIREMENT	REMARKS
FROST REMOVAL	The accretion of frost or ice internally or on the surface shall be prevented.	Ice formation will stiffen the facepiece resulting in discomfort due to loss of flexibility. Ice formation will also add weight to the facepiece which will tend to introduce instability. Blockage of the respiratory pathway will increase breathing resistance or prevent breathing. Ice will also prevent mask adjustment during wear.
RETENTION/STABILITY	The mask shall be firmly retained on the wearers head and not subject to movement on the face due to head and jaw motion, body dynamics or equipment dynamics, or high wind velocity.	Instability will result in facial irritation and can interfere with sensory perception. Instability may also result in interference with the use of military equipment and may cause loss of insulative protection to the face. The mask should not move when talking, walking, jumping or when exposed to vehicle vibrations. Movement of the mask could interfere with vision.
	Wear of the mask shall not result in the instability of other clothing or equipment.	Helmet or other equipment used on or around the head depends on stabilization for adequate performance. Mask induced instabilities will degrade performance.

TABLE III (continued)

OPERATIONAL REQUIREMENTS

DESIGN CRITERIA	REQUIREMENT	REMARKS
DONNING/DOFFING	Shall be donned or removed without assistance.	The individual soldier may be operating alone when the need for protection occurs. Other protective equipment is designed for self donning.
	Shall be donned or removed while wearing gloves and/or mittens.	At extremely cold temperatures the fingers become painfully cold when exposed even for short durations of time. This is especially true if the bare hand is expected to handle cold-soaked equipment or clothing.
	Shall not require special training or extensive indoctrination in the donning and adjustment of the mask.	Simplified designs minimize improper use and hazard of frostbite. The mask should feel comfortable only when properly donned.
DURABILITY	The face mask shall be suitable for reuse and its protective performance shall not be degraded due to aging or wearing out. The mask shall not become damaged as a result of any prevailing environmental conditions.	Logistics and cost considerations require that the mask be reusable. Loss of protection due to damage during wear is unacceptable because of the potential irreversible injury of frostbite and the unacceptable loss of manpower due to this form of injury. The durability must be equivalent to other items of cold weather clothing. The mask is to have an extended shelf life with no loss of protection and is to withstand extensive donnings and washings.

TABLE III (concluded)

OPERATIONAL REQUIREMENTS

DESIGN CRITERIA	REQUIREMENT	REMARKS
LAUNDERABILITY	Shall be reusable after cleaning by typical clothing laundry techniques by the user in the field.	Launderability required to ensure hygienic acceptability due to biological wastes (saliva, sweat, sebum etc.) Reuse of a dirty mask results in wearer rejection. A single use throwaway mask increases cost and logistics penalties.
PRODUCIBILITY	Shall be suitable for production in large quantities using readily available fabrication materials and a minimum of new tooling or complex fabricating equipment.	Requirement for low cost prohibits the introduction of new and costly fabrication techniques. The use of existing fabrication facilities will ensure availability in the shortest time period and without the need for extensive manufacturing training programs. The manufacturing techniques must be consistent with uniform quality.
CARRIAGE (Portability)	Shall be designed for carriage by the user without the need for special containers or equipment for mounting on the user and shall be compactable to facilitate carriage by the user.	The need for facial protection will depend on the tasks/environment relationships which prevail. Thus, the mask must be immediately available for donning. Special containers will add to the bulk/weight burden already imposed on the foot soldier. If the mask can be compressed into a small size then it can be carried in available containers used for other purposes (eg. pockets, load carrying packs, etc.). The method of carriage should protect the mask against moisture.

TABLE IV

PSYCHOPHYSIOLOGICAL REQUIREMENTS

DESIGN CRITERIA	REQUIREMENT	REMARKS
VISION	Shall not impede wearer's visual field.	Data are unavailable for determining acceptable degrees of visual field impedance on the basis of visual performance. However, impedance by other head-mounted equipment is reported by users as being unacceptable. Impedance will increase the need for compensatory head movements, will contribute to a reduced level of wearer acceptance, and will decrease the probability of target detection in the peripheral field.
	Shall permit placement of optical equipment within the design clear-eye distance.	Most fire control optical sighting devices are designed for use with the objective located very close to the eye (approximately 0.5 in. to accommodate all devices). Visual occlusion occurs when the device distance exceeds the design distance.
	Shall not permit the freezing of moisture on eyelashes.	This is cited as a problem in extremely cold environments where lashes freeze thus keeping the eyes effectively closed.
	Shall not significantly impede the transmission of visible light to the eyes.	The capability should be preserved for maximizing light transmission to ensure target detection especially under poor illumination conditions. Many tasks require good visual acuity (reading dials and scales) which can be degraded with large reductions of light transmission. However, this requirement does not preclude the need for visual protection against glare.

TABLE IV (continued)

PSYCHOPHYSIOLOGICAL REQUIREMENTS

DESIGN CRITERIA	REQUIREMENT	REMARKS
HEARING/TALKING	Shall not interfere with speech.	Immobilization of the jaw or lips by the mask will prevent the generation of intelligible sounds.
	Shall not attenuate the transmission of acoustical noise to a degree where intelligibility is decreased below acceptable limits.	The continued ability to communicate effectively in the environment is necessary to maintain the required levels of task performance. This requirement includes face-to-face conversation, transmission of commands over reasonable distances and the ability to couple the mask with communications equipment. In addition to vocal sounds there is a need to hear other sounds from the environment such as gunfire, vehicles, whistles, etc.
PHYSIOLOGICAL ACCESS	Shall not permit the accumulation of moisture within the protective envelope.	Perspiration (either sensible or insensible) can accumulate within a mask at rapid rates. Additionally saliva and respiratory moisture will add to this burden. While the primary problem due to moisture is discomfort, permeable materials will tend to wick the water to the facepiece surface where freezing can occur.
	Shall permit the removal of oral and nasal excreta.	The production of nasal discharge materials and sputum will necessitate some means for elimination. Access to the nose to permit "blowing" and to the mouth for spitting are implied requirements.

TABLE IV (continued)

PSYCHOPHYSIOLOGICAL REQUIREMENTS

DESIGN CRITERIA	REQUIREMENTS	REMARKS
PHYSIOLOGICAL ACCESS (continued)	Shall permit eating and drinking.	Prolonged periods of exposure to windchill conditions will require that the wearer consume food and liquids while protected. To ensure minimum loss of protection during this operation the area of facial exposure must be restricted. Since special drinking and eating equipment is not planned then the width of the opening shall be not less than mouth width. For food consumption the length need not exceed lip thickness provided a stretch material is used to permit lengthening the opening when the mouth is opened.
	Shall permit the removal of fluid and foreign materials from the eyes.	A Access to the eyes will be required during mask wear, however, the duration of exposure to windchill is to be minimized. One potential problem is removal of eyelashes from the eye surface. Eye fluid drainage must also be removed for comfort.
HEAD MOVEMENT	Shall not impede head mobility in any axis.	Restriction of head movement will degrade the performance of many tasks. Visual tasks such as seeing the ground around the feet is a typical problem when the head has downward motion restriction. Additionally, during use of a parka the head moves and rotates within the protected envelope. Protrusions from the mask will tend to snag the parka material thus limiting head movement.

TABLE IV (concluded)

PSYCHOPHYSIOLOGICAL REQUIREMENTS

DESIGN CRITERIA	REQUIREMENTS	REMARKS
RESPIRATORY	Shall provide adequate respiratory exchange with the environment.	The normal respiratory exchanges with the environment are to be ensured by the mask. The inhalation of air will provide sufficient oxygen for physiological functioning at all activity levels. However, excessive breathing resistance or dead space within the breathing chamber will limit the acceptability of an open-cycle breathing loop. Respiratory resistance and CO_2 concentrations of inhaled air are to be minimized.
	Shall not restrict the capability of the wearer to sense odors.	Environmental odors are indicative of equipment operating performance and the existence of potential hazards. Additionally, the mask materials shall not possess noxious odors which will increase rejection by the wearer and could prevent the detection of environmental odors.
COMFORT/ACCEPTABILITY	Shall not cause wearer discomfort or induce any feeling of lack of confidence in the user.	Acceptability of the protective device can only be ensured when the wearer is willing to rely on the device for protection at all times. Any performance decrement or task incompatibility which occurs will tend to limit the degree of acceptance.

personnel. Because of logistics problems and increased production costs associated with multiple sizes, the basic design concept is to minimize the number of sizes necessary to meet this requirement.

The following data on the distribution of face and head dimensions were selected to provide a quantitative basis for sizing of the cold weather mask:

	PERCENTILE-INCHES				5-95% RANGE	REFERENCE
MEASUREMENT	1st	5th	95th	99th	(inches)	
Head Circumference	20.63	21.07	23.16	23.61	2.09	(12)
Bitragion-Min. Frontal Arc		11.2	12.8		1.6	
Bitragion-Menton Arc		11.8	13.7		1.9	
Bitragion-Subnasal Arc		10.5	12.2		1.7	
Interpupillary Distance	2.06	2.15	2.67	2.80	0.52	(12)
Facial Length	4.14	4.13	5.17	5.37	0.86	(12)

Use of the 5th through 95th percentile range data was the initial approach for developing the basic facepiece pattern. It had been assumed that the use of elastic materials would further accommodate larger-sized faces and that simple adjustment and/or facepiece trimming could take up slack for smaller-sized faces. This would permit adequate fit for 98% of the population.

PHYSICAL

WEIGHT/VOLUME

The current standard cold weather mask weighs approximately 3 ounces and can be folded to fit in many of the pockets of the cold weather uniform. Subjective trials with the standard mask and personal communications with personnel from the Natick Laboratories (13) indicated no objection with the weight and volume of the current mask. Therefore, the weight and pocket carriage characteristics of the current standard mask were established as "not-to-exceed" requirements for the new mask. Initially a 4-ounce weight limit was established as a contractual requirement.

ELECTROSTATIC CHARACTERISTICS

If the face mask should develop an electrostatic potential it can interfere with vision by making the fur ruff of the hood stand on end potentially covering some of the field of vision. It can also cause discomfort and interference by attracting other items of clothing or particulate matter in close proximity to the mask and possibly drawing an electrical arc when contacted by a grounded piece of equipment. Therefore, the prototype face mask shall be made of materials which will not develop an electrostatic potential greater than the materials used in the cold weather ensemble.

COLOR

The Arctic cold weather uniform includes a white overgarment to be used for camouflage purposes in snow covered areas. To maintain the camouflage continuity, the cold weather face mask shall also be white in accordance with existing camouflage policy for snow covered areas.

ENVIRONMENTAL CHARACTERISTICS

Use of the cold weather mask is intended for any conditions involving a windchill environment. The cold extremes for the operation of military equipment are specified by AR70-38, "Research, Development, Test and Evaluation of Material for Extreme Climatic Conditions", and were used as requirements for the cold weather mask.

Storability

The mask shall be storable at temperatures to -65°F and shall not be damaged or lose its protective capability when flexed at these temperatures. During storage, temperatures can be expected to vary over a period of time, the range depending on geographical location. High temperature storage should be assumed for part of the life cycle especially during transit.

Flexibility and Compliability

The mask shall retain both flexibility and compliance when exposed to c cold temperatures. Donning of the mask can be expected when the mask has been cold soaked. During wear these characteristics are to be maintained to ensure comfort and good fit.

Weather Resistance

In addition to the temperature (-65°F) and wind velocity (35 mph) requirements, the mask must remain durable and functional when exposed to rain and driven snow. Ice formation or material wetting shall not degrade its protective performance.

Section IV

CONCEPT SYNTHESIS

The synthesis of concepts for cold weather protective masks was conducted as a parallel task with the requirements analysis process. As the basic functional requirements were converted into detailed performance requirements, concepts were generated which had the potential for providing the necessary performance. The concepts were then analyzed in the light of the performance requirements to derive design requirements for mask prototypes.

The development of actual concepts concentrated on three aspects of mask design. The first of these, that of providing protection, dealt with the means of maintaining adequate skin temperature in the protected area and preventing excessive heat loss. The next, configuration concepts, was concerned with how the mask would be designed to provide the necessary protection while being compatible with equipment operations and other mask functional and performance requirements. Material selections, the third design aspect, were then made on the basis of both the configuration and protection concepts.

PROTECTION

The requirements analysis provided estimates of acceptable skin temperatures and the associated heat loss rates for various environmental conditions. Using the concept of providing an insulating layer between the skin and the environment to restrict heat loss and raise skin temperature, an analysis was conducted to determine the required thermal characteristics for the insulating layer. The concept of providing a dead air layer adjacent to the skin as an insulating barrier (Wood-Haferty concept) (14), was rejected in favor of placing an insulating material directly in contact with the skin. The design complexity and the overall bulk associated with providing the dead air layer were judged prohibitive.

The requirements analysis showed the necessity of preventing leakage of ambient air between the mask and the face. This suggested that the mask should be close-fitting, and that under the most severe environmental conditions (-65°F and 35 mph wind) should be effectively sealed against the face. A commercially-developed, oronasal respirator was chosen to provide the seal over the nose and mouth region; the mask provided a complete covering and had sufficient resistance to flow to effectively attenuate a 35 mph wind.

The concept of providing a transparent, protective covering over the eyes as an integral part of the mask was contrasted with that of depending upon the existing goggles to provide that function. It appeared more reasonable and cost-effective to use the existing goggles. Under relatively mild exposure conditions it would be acceptable to wear the mask without the goggles.

It was decided to extend the mask rearward to cover the wearer's ears. This was done to provide greater flexibility in the use of the mask; it permitted the mask alone to provide head protection under more severe environmental conditions than would be acceptable if ear coverage were not provided.

Subjective comfort can be attained at higher windchills with only the face and ears covered than with the insulating cap alone due to the relatively high heat loss rate for the nose, cheeks, and chin.

The overall area of coverage of the mask was selected to provide an overlap between the mask and the insulating cap. The overlap was to improve the seal against ambient air flowing between the head/face and the mask/cap and thus improve the overall protection effectiveness of the assembly.

The requirements analysis raised the question as to whether the mask should be permeable or impermeable to moisture. Due to lack of data, the question could not be resolved by analysis alone and it was elected to fabricate mask samples with varying degrees of permeability, and to resolve the question during evaluation of Phase I prototypes.

CONFIGURATION

The protection concept called for an insulative type mask which could prevent the flow of ambient air between the mask and the face. Requirements for compatibility with equipment and operations suggest that the mask add as little bulk to the face as possible.

FACEPIECE

The configuration concept selected to satisfy these requirements was a close-fitting mask constructed of an insulating material whose thermal conductivity was low enough to permit high insulating value with minimum thickness. To insure a close fit consistent with minimum bulk and good sealing against ambient air leakage, the mask facepiece was to be made of an elastic material. The elastic when stretched over the face by the retention harness would conform well to the basically convex facial contours and would provide sufficient "give" to accommodate itself to a range of facial contours.

Special provisions were required at the sides of the nose where the face has a concave contour. Consideration was given to either padding the mask or providing a structural member in this region to eliminate the gaps which would occur if the mask facepiece were stretched over the nose and cheeks. The padding concept was inconsistent with the requirement for minimum bulk added to the face and was, therefore, eliminated in favor of the concept of providing a structural member to resist the facepiece tension forces and hold the mask against the sides of the nose and the cheeks.

FACEPIECE STABILIZATION

Experience with facepiece design (15) had shown the necessity for some stabilization in the vertical direction to resist the accelerations in this direction due to walking, running, and riding in vehicles. Experience had also shown that a concept in which the wearer's chin fits into a pocket or cup in the mask and the mask is held in place by an upward and backward pull is adequate for stabilization. In this concept, the retention harness is configured to provide sufficient "bootstrapping" to hold the mask firmly in position; the harness applies forces to the top and back of the head and

the forces are reacted through the forehead area of the mask and through the portions of the mask which bear on the front and underside of the chin. The so-called chin/forehead indexed mask concept was chosen for application to the cold-weather protective mask.

ADJUSTABILITY

Although the requirement stated a minimum of three sizes a single size mask would be more logistically desireable. In order to accommodate a range of facial contours and dimensions in a single size mask, considerable compliance or adjustment is required.

An investigation of the need for adjustment in the cold weather mask revealed that it was dictated primarily by the need to consistently locate the facepiece with respect to the wearer's eyes. If the facepiece and the visual port could be properly located, the size of the visual port, and, thus, the exposed flesh area in the ocular area could be minimized.

The concept of a flexible, elastic facepiece permitted the mask to be located laterally with respect to the eyes with no difficulty, and the head shape is such that there is no tendency for the mask to shift laterally once it has been positioned.

The combination of a need to provide vertical location for the mask over the eyes, a chin indexing concept for the mask and the normal variation in wearer's face length led to the design requirement that adjustment be provided for the mask facepiece dimension between the bottom of the chin pocket to the visual port. Designs were investigated during the program which could satisfy this requirement.

MATERIALS SELECTION

Material performance requirements were developed in conjunction with the concept synthesis task. The performance required of materials to be incorporated within the cold weather mask depends upon both the overall mask performance requirements and upon the specifics of the mask design concept. None of the materials initially investigated appeared to satisfy all of the requirements. It was decided, therefore, to select materials on the assumption that the facepiece would be composed of a laminate. One layer was to provide insulation while other layers would provide strength, moisture absorption, color, feel, and elasticity.

INSULATING MATERIAL

Table V presents parameters which were judged relevant to the selection of insulating materials for a wrap-around-type cold weather protective mask.

Rather than attempt to derive discrete performance requirements for each material characteristic listed in Table V, relative judgements were made. Scoring procedures were established for each material characteristics such that each material could be assigned a score depending upon its "goodness" or badness" regarding each characteristic. When materials listed

TABLE V

INSULATING MATERIAL CHARACTERISTICS

1. Density---weight of material per cubic foot of volume

2. Thermal Conductivity---$Btu/hrft^2F^o/in$

3. Compression Set---the amount of thickness a material fails to regain after a given load or deflection has been removed. Unless otherwise noted, the test conditions are a 50% compression for more than 20 hours at room temperature. For example, a 10% set means that the material regains only 90% of its original thickness after the load is removed.

4. Compressive Strength---the pressure necessary to cause a 25% (or 50%) deflection.

5. Tear Strength---force necessary to cause a tear.

6. Tensile Strength---maximum load before failure.

7. Surface Texture and Feel---subjective description of surface characteristics and flexibility.

8. Moisture Permeability---the quantity of water vapor which can be transmitted through the material. Units are in perm-inches.

9. Moisture Absorbtion---the quantity of liquid water absorbed when completely submerged in water.

10. Electrostatic Characteristic---the dielectric constant of the material which is an indication of the susceptibility of the material to pick-up a static charge.

11. Production Qualities---factors relating to the materials manufacturing characteristics.

12. Low Temperature Properties---suitability for use at extremely low temperatures.

13. Availability---commonly available sizes and shapes.

14. Cost---dollars per cubic inch of material.

15. Color---color in which the material is normally available.

16. Odor---subjective.

TABLE V (concluded)

INSULATING MATERIAL CHARACTERISTICS

17. Allergenic Reactions---indicates any known allergenic responses associated with the material.

18. Aging Effects---the effect of time on the condition of the material.

19. Flammability---an indication as to whether the material will burn.

20. Specific Heat---units in either Btu/lb^{o}F or cal/gm^{o}C.

in Table VI were evaluated, many were found entirely unsuitable for use in the mask. A low-density open-cell, polyurethane foam, and a low-density polyester felt were ultimately selected for use as insulating materials. Closed-cell polyurethane and closed-cell neoprene were also selected to provide an evaluation with respect to moisture permeability.

BACKING LAYERS

Knit, stretch nylon was chosen to provide the necessary strength and durability for the facepiece. Knit materials were also chosen for the comfort layer between the face and the insulating material because of the design requirement that the overall laminate have sufficient stretch to conform well to facial contours. Cotton jersey, stretch nylon, and a knit polypropylene fabric were among those considered for use as the comfort layer. A neoprene coated stretch nylon was also included as part of an evaluation of the need for permeability.

TABLE VI

POTENTIAL MASK INSULATING MATERIALS

1. Elastomer Foams, Flexible
   a. neoprene foam
   b. polyethylene foam
   c. polyvinyl chloride foam
   d. natural rubber foam
   e. silicone rubber foam
   f. urethane foam

2. Plastic Foam, Rigid
   a. cellulose acetate foam
   b. phenolic foam
   c. polyethylene foam
   d. polyvinyl chloride foam
   e. polystyrene foam
   f. urea formaldehyde foam
   g. urethane foam

3. Loose Fill Insulation
   a. silica-aerogel
   b. glass fibers

4. Natural Fiber Felts
   a. cotton
   b. cotton wool
   c. wool

5. Synthetic Fiber Felts
   a. acrylic felt
   b. dacron polyester felt
   c. nylon felt
   d. polypropylene felt
   e. polyvinyl chloride felt
   f. rayon viscose felt

6. Rubber
   a. natural latex
   b. butyl
   c. hypalon
   d. silicone rubber

7. Natural Fiber Fabrics
   a. cotton
   b. linen
   c. wool
   d. silk

8. Synthetic Fiber Fabrics
   a. nomex nylon
   b. nylon
   c. rayon
   d. glass
   e. acetate
   f. olefin
   g. polyester

Section V

PROTOTYPE DESIGN AND EVALUATION

The candidate concept and materials were combined via the design development process to produce a number of preliminary mask prototypes. The design development involved both analytical trade studies and iterative development of design details through "cut and try" techniques. The resulting nine different Phase I prototype masks were evaluated at Synsis and submitted to the U.S. Army Natick Laboratories for additional investigation. The evaluations resulted in the selection of two of the preliminary prototypes for further development and a set of recommendations for changes to be incorporated in the selected designs.

PROTOTYPE DESIGN

Several elements of the prototype design were developed somewhat independently and later integrated into a complete mask. These elements included: 1) the facepiece, 2) an adjustment feature to compensate for variable face lengths among wearers, 3) a harness system incorporating adjustment for head circumference variation, 4) a visual port in the facepiece, and 5) a removable oronasal barrier. Specific material laminates and fabrication techniques were also selected.

FACEPIECE DEVELOPMENT

The Canadian cold weather face mask (Figure 11) was used as the basepoint for the development of a facepiece design and pattern. The attractive feature of the Canadian mask was the use of stretch material which would mold itself to facial contours without the necessity of complicated darts, tucks, etc. The stretch material also accommodated itself to a wide range of contours.

Figure 12 depicts an initial facepiece constructed of elastomer foam using the Canadian mask pattern. Modifications were made in the original pattern to provide for a chin pocket and additional coverage for the oronasal area. The chin pocket provided a means of stabilizing the mask on the face; the harness straps were arranged to exert an upward and backward pull on the facepiece to keep the chin pocket firmly seated on the chin and against the forehead.

Modifications were made to improve the fit of the mask to the face. Darts were tried at the edge of the facepiece along the jaw line; it was eventually determined that one dart per side provided an acceptable fit in this area. It was also determined that the ability of the facepiece to conform to facial contours was considerably improved by the addition of edge binding or other provision which made the periphery stiff in tension relative to the remainder of the facepiece. A row of stitching at the periphery was found to be sufficient to produce the effect.

FACE LENGTH ADJUSTMENT

The mask concept described in Section IV calls for a single-size mask

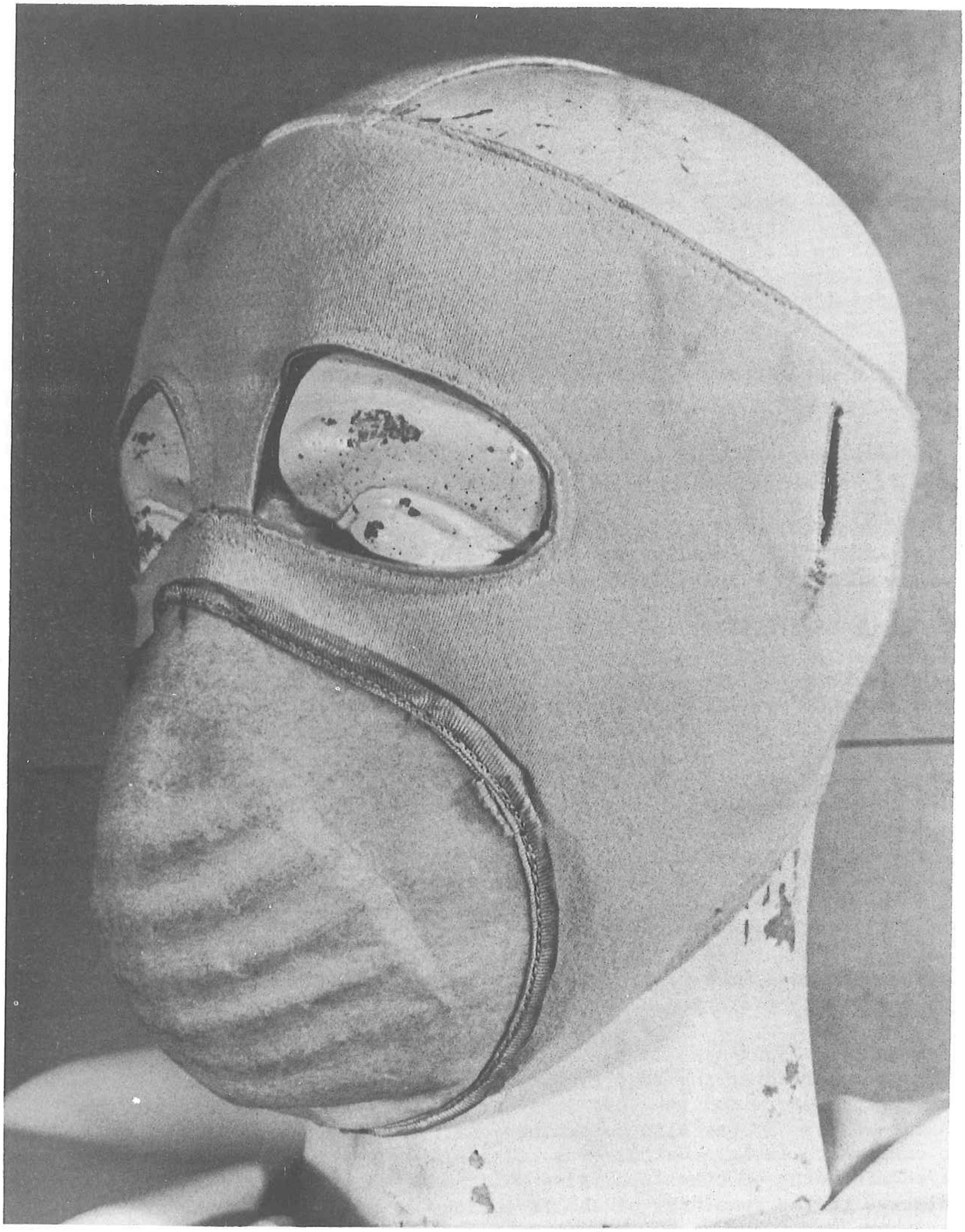


Figure 11. Canadian Cold Weather Face Mask

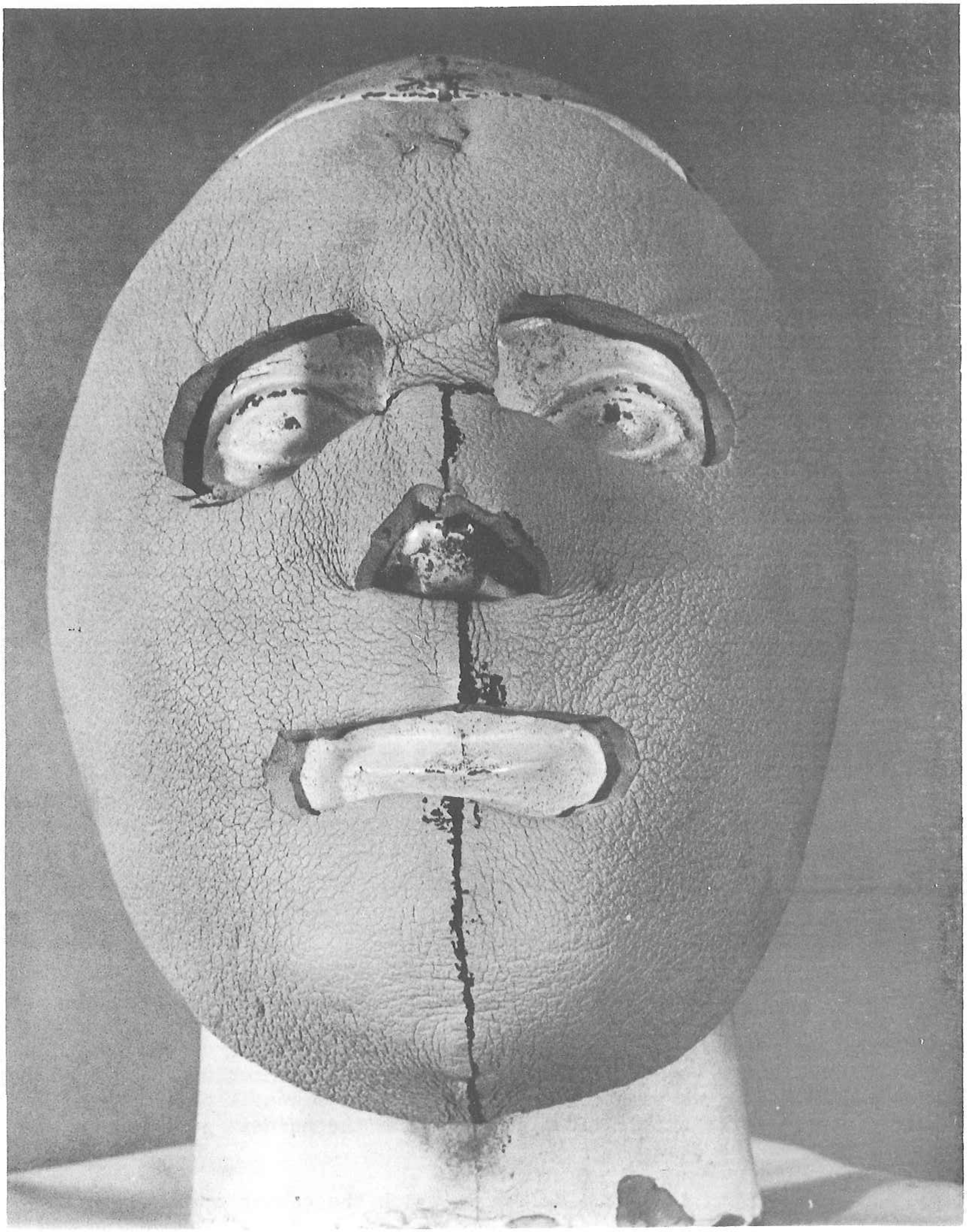


Figure 12. Initial Facepiece Pattern Constructed of Elastomer Foam

to fit all U.S. Army field personnel, and for an adjustment feature to permit the visual port of the mask to be centered over the wearer's eyes. The adjustment is to allow for the fact that the mask is indexed by the chin pocket for stability but must be positioned with respect to the eyes to permit adequate vision. Variations across the population in the vertical distance from the chin to the eyes is sufficient to require that adjustment be provided.

Figure 13 shows an approach that was tried for providing adjustment; the facepiece was slit at either side of the oronasal opening and adjusted for chin-pocket-to-eyeport length by varying the amount of overlap between the upper and lower parts. Hook and pile fastener tape was used to provide attachment at the overlap. Figure 14 shows a variation of the approach in which two sets of slits were provided - one at the mouth port and another at the sides of the visual port. Both of the approaches were rejected because of the bulk added by the overlaps, the likelihood of cold air leakage past the overlaps and the fact that neither the goggles nor the oronasal barrier could be made to seal effectively against the outer surface of the overlaps.

Figure 15 shows an early version of a design concept for face length adjustment that was eventually adopted for the Phase I prototypes. Here the variable overlap is located under the chin area leaving the cheek and temple areas of the mask clear and flat. The same overlap principle applies but the adjustment actually forms the chin pocket of the mask. The arrangement of the flaps is such that no gaps exist for air leakage. As the extent of overlap is varied, the position of the resulting chin pocket varies with respect to the visual port location.

HARNESS DESIGN

The function of the retention harness as described previously is to apply forces to the facepiece which tend to keep it in contact with the face and prevent it from moving under the influence of externally applied forces. The design concept for this program required the harness to apply an upward and backward directed force to the facepiece in order to provide the desired function.

Configuration

A simple harness attaching to both sides of the mask and passing around the rear of the head was tried initially, but because of typical head shapes, the design could not provide a consistent upward force on the facepiece A modification of the single strap design was made to add a center strap between the forehead region of the facepiece and the center of the backstrap. This modification was adopted for the prototypes since it provided the required upward force on the facepiece and made the harness position stable on the back of the head.

Figures 16 and 17 show a design in which the center strap was bifurcated to help keep it centered over the top of the head. The design was not found to be effective in keeping the strap centered. Figure 18 shows a design which was more effective in keeping the top straps positioned but which was judged as too complex to be justified by the slight improvement

Figure 13. Facepiece Adjustment Approach Using Slits to Compensate for Face Length Variation

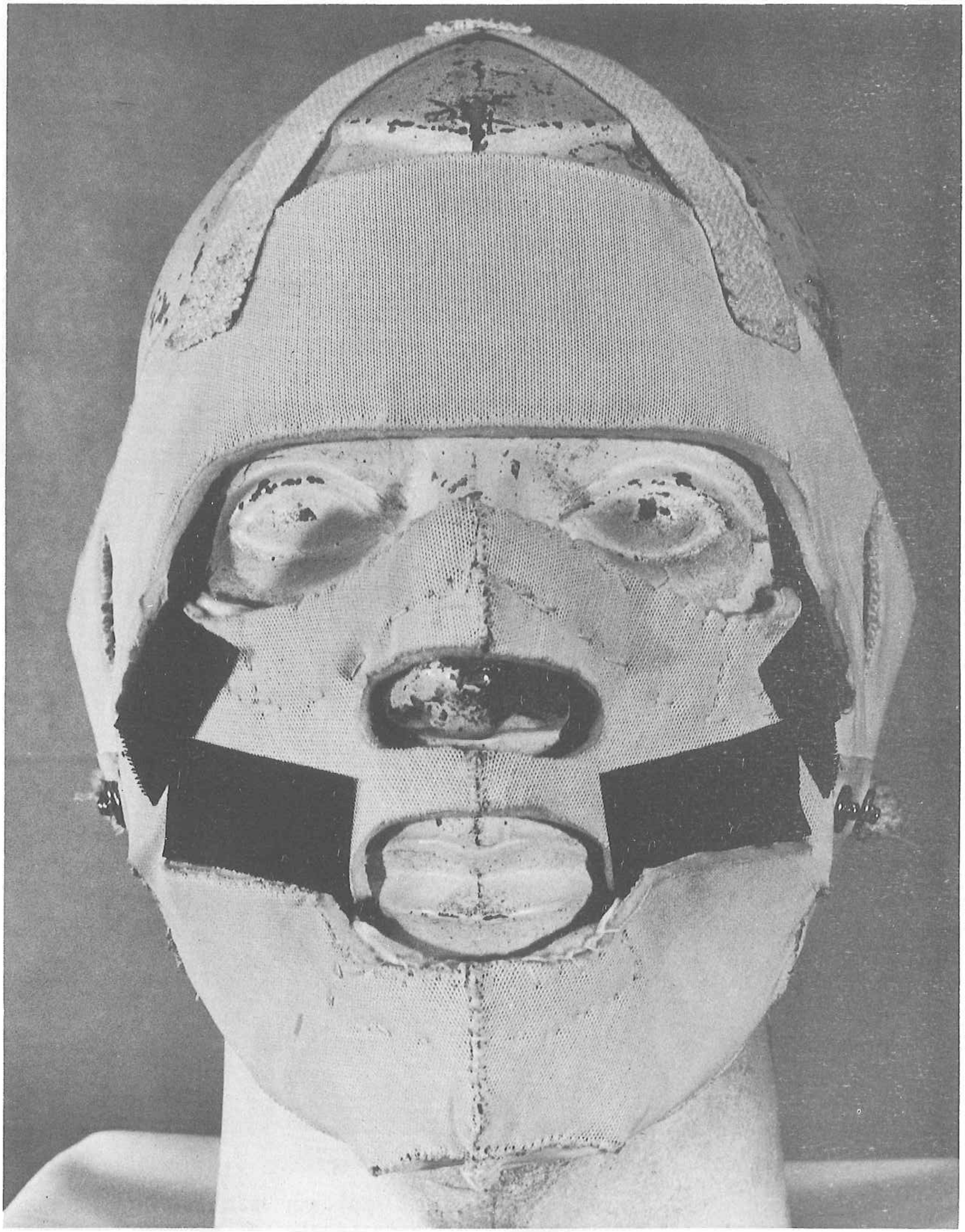


Figure 14. Facepiece Adjustment Approach Using Dual Slit Technique

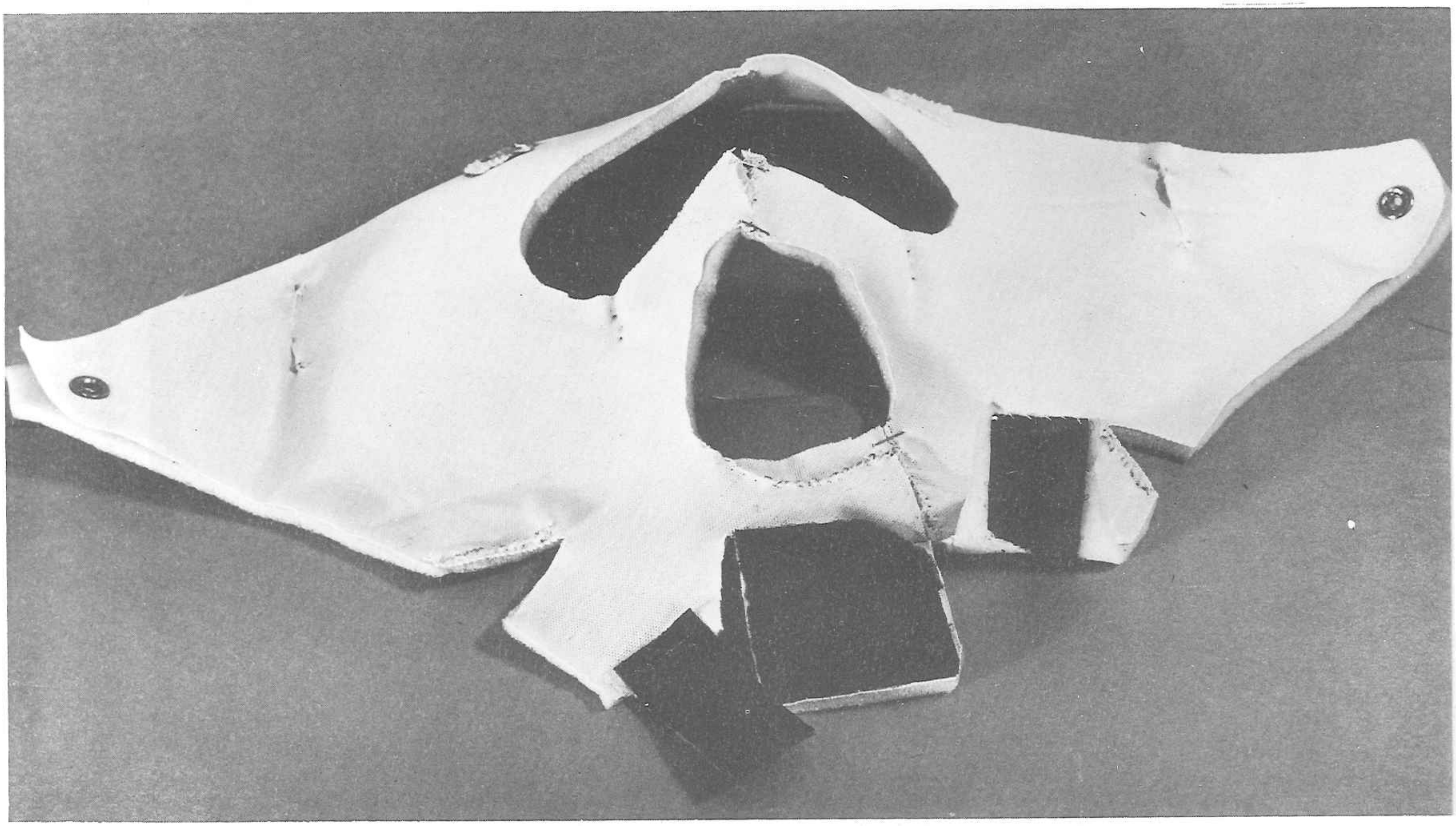


Figure 15. Design Concept for Face Length Adjustment

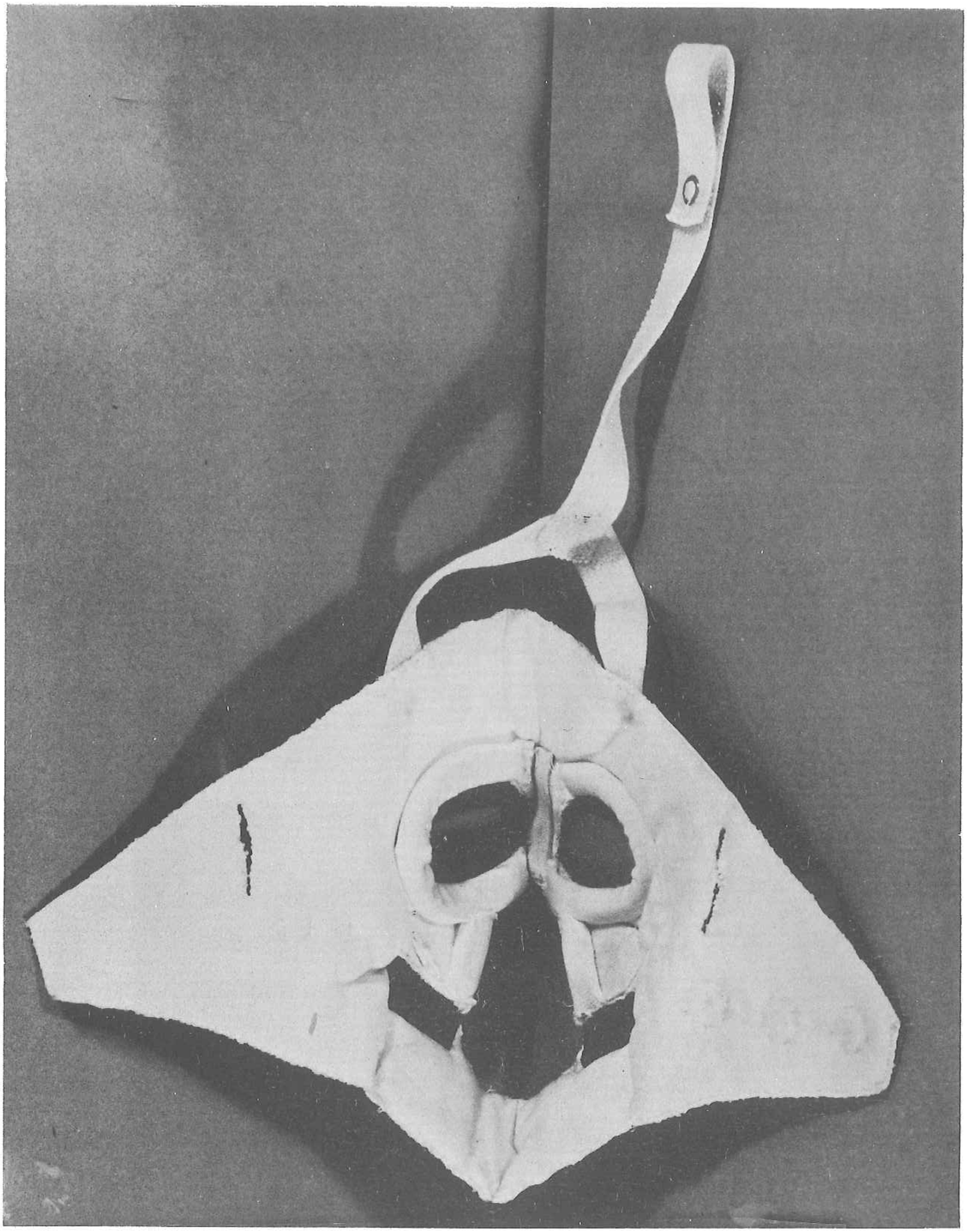


Figure 16. Retention Harness Concept
Using Bifurcated Center Strap

Figure 17. Rear View of Retention Harness Concept Showing Adjustment Technique for Strap Centering

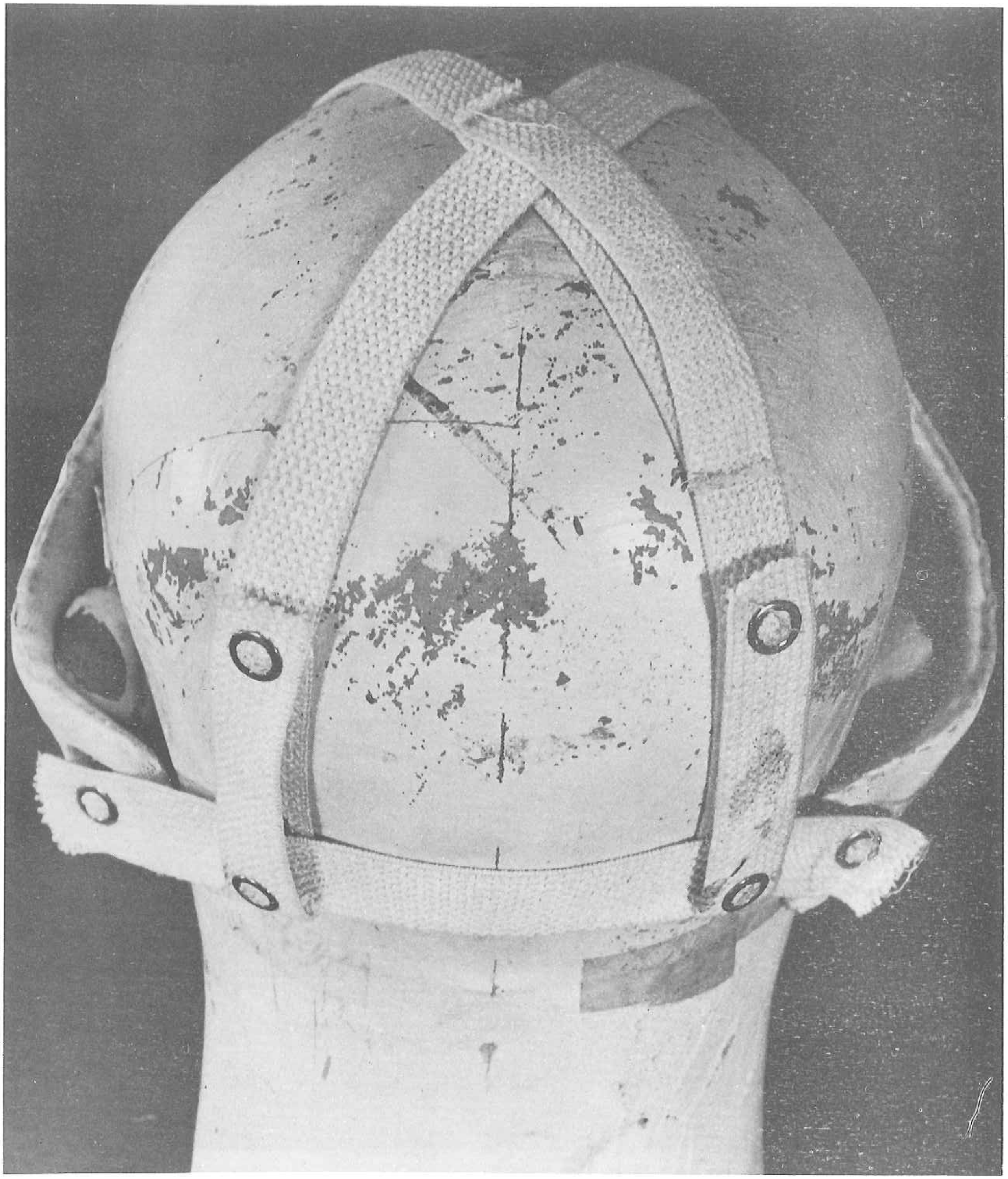


Figure 18. Retention Harness Concept for Strap Centering on Head

in the overall harness performance.

Adjustment

Adjustment is required in the retention harness to accommodate a large range of head sizes. As mentioned in Section III, the range can be about 3 inches. Consideration was given to simply making the harness of elastic webbing material and permitting the range of head sizes to be accommodated by variable stretch in the harness. The amount of stretch required to permit this design approach was excessive, however.

Evaluation of the adjustments shown in Figures 16 through 18 revealed that the strap over the crown of the head did not have to be adjustable if the strap was elastic. The back strap, however, in addition to requiring adjustability, needed to be detachable to facilitate donning and doffing. It appeared to be acceptable to permanently attach the center strap to the back strap and to provide adjustment and attachment between the back strap and facepiece on one side only. Hook and pile fastener tape was used for the attachment and to provide adjustment.

VISUAL PORT

The visual port and the immediate surrounding area of the facepiece are required to permit relatively unimpeded vision and to be compatible with the use of corrective lenses, goggles and other pieces of optical equipment. There is also a requirement to protect the ocular area against cold, wind, and blowing snow. The requirements are contradictory in that one calls for a relatively large visual port while the other suggests that the facepiece should cover as much of the ocular area as possible.

A compromise was struck between these requirements with the rationale that goggles or corrective lenses could provide a part of the ocular protection under severe environmental conditions, but that good vision was required under all environmental conditions. The emphasis was placed on providing a wide field of vision and good accommodation of goggles, glasses and optical equipment. Since the face length adjustment feature was to permit the facepiece to be positioned with respect to the eyes, the eyeport needed only to be large enough to accommodate large facial dimensions in this region. There was no need to make the port oversize to allow for gross misalignment of the facepiece on the face.

Sizing

The visual port dimensions were developed through consideration of anthropometric data and by fitting on a large headform. The headform was measured and found to have a biocular diameter approximately equivalent to the 99th percentile value (12). Inspection of facepieces fitted to the headform led to the selection of 4.5 inches as an appropriate dimension between the lateral extremes of the eye port. Vertical dimensions and contours for the opening were initially established by reference to the headform and were then checked on a small number of human subjects. Experimental data necessary to objectively validate the design were not available.

Configuration

To provide structural continuity across the eye port, it is necessary to connect the upper and lower edges, in some fashion, at the mask centerline. In the Canadian mask (Figure 11) this is accomplished by extending a tab of facepiece material from the upper edge of the opening and attaching it to the lower edge. In masks developed under this program the tab was replaced by a slender, elastic strap.

The strap interfered considerably less with the central position of the binocular visual field and also permitted the eyeglasses to fit against the nose bridge rather than being displaced forward as is the case with the Canadian and the standard U.S. Army cold weather masks. It was also found to be feasible to insert the glasses behind the strap so that they are firmly held in position on the nose bridge.

Nose Bridge Stiffener

It is necessary for the facepiece to fit closely against the face to provide adequate protection. In the nose bridge area, accommodation of goggles and glasses also requires a close fit of the facepiece against the nose and face. It is necessary to prevent exhaled air from flowing between the face and the facepiece into the eyeport region to prevent moisture from condensing on the back side of the goggles or eyeglass lenses.

A malleable, metal stiffener was incorporated into the area of the facepiece which passes over the bridge of the nose and forms the lower perimeter of the eyeport. The stiffener permitted the facepiece to be molded with the fingers into a shape which followed the facial contour. Both wire and sheet metal were tried for use as a stiffener, but the thin sheet was found to be preferable.

ORONASAL BARRIER

Protection of the face against cold, wind, and blowing snow requires that facial areas be covered to conserve body heat. Eating, drinking, spitting, blowing the nose, etc., require that access be provided to the nose and mouth. Providing a section of the mask which can be removed or pulled away from the oronasal region satisfies the requirements, and the concept has been used on a number of masks developed in the past (1).

A relatively inexpensive, commercially available nosecup respirator was chosen for use as the removable cover for the oronasal region. The respirator had the advantage of being a three-dimensional shape which could be molded to conform well to a wide range of facial contours. In addition, the respirator, which was originally developed as a temperature-control mask, was capable of maintaining inhaled air temperature at well above ambient. Experience with low temperature environments has shown that inhalation of very cold air is unpleasant and, at times, painfully distracting.

The concept of using the respirator as a separate part from the face mask was considered. The head harness supplied with the nosecup was, however, found to be inadequate for keeping the nosecup in position. For the

Phase I prototypes, the nosecup strap was cut, one side permanently attached to the facepiece, and the other side fastened to the facepiece via a hook and pile fastener tape arrangement.

PHASE I PROTOTYPE MASKS

Results of the Phase I conceptual design effort were reviewed with the Project Officer from the U.S. Army Natick Laboratories and mask configuration approaches to be evaluated for detail design and development during Phase II were selected. The initial selection resulted in a mask configuration incorporating many of the most promising concepts summarized by the foregoing information. Figures 19 and 20 illustrate the Phase I configuration which was fabricated in nine different models combining several candidate fabrication materials. Table VII summarizes the material combinations used for each model.

Configuration Description

The Phase I prototype mask was designed as a one-piece, close fitting mask. This mask used the chin pocket adjustment technique which provided a single-sized mask which could be adjusted to fit the U.S. Army population. These masks incorporated the following additional features :

1. A single, large visual port sized to provide good visual field and adequate protection.

2. Mounting provisions for eyeglasses including an elastic strap for retention on the nose bridge and additional loops at the sides of the mask for retention of the eyeglass stems.

3. A malleable stiffener in the nose bridge area to be molded with the fingers to provide a good fit in this area for accommodation of goggles and eyeglasses and prevention of exhaled air leakage.

4. An oronasal opening covered by an oronasal respirator. The respirator was permanently attached to the facepiece at one side but attached through hook and pile fasteners at the other side to permit displacement of the mask for eating, smoking, spitting, nose blowing, etc.

5. An adjustable and detachable head harness to facilitate donning, doffing and adjustment for individual head size.

Material Applications

The nine Phase I models were similar in design varying only in the materials used to fabricate the facepiece as shown in table VII. Two of the masks (# 2 and # 4) used an impermeable construction. Most of the masks used a stretch, knit nylon for the outer lay because of its unique combination of elasticity, mechanical strength, and durability. Similarly, most of the models used cotton jersey for the inner layer because of its ability to wick away moisture. An alternative inner layer was also used because of

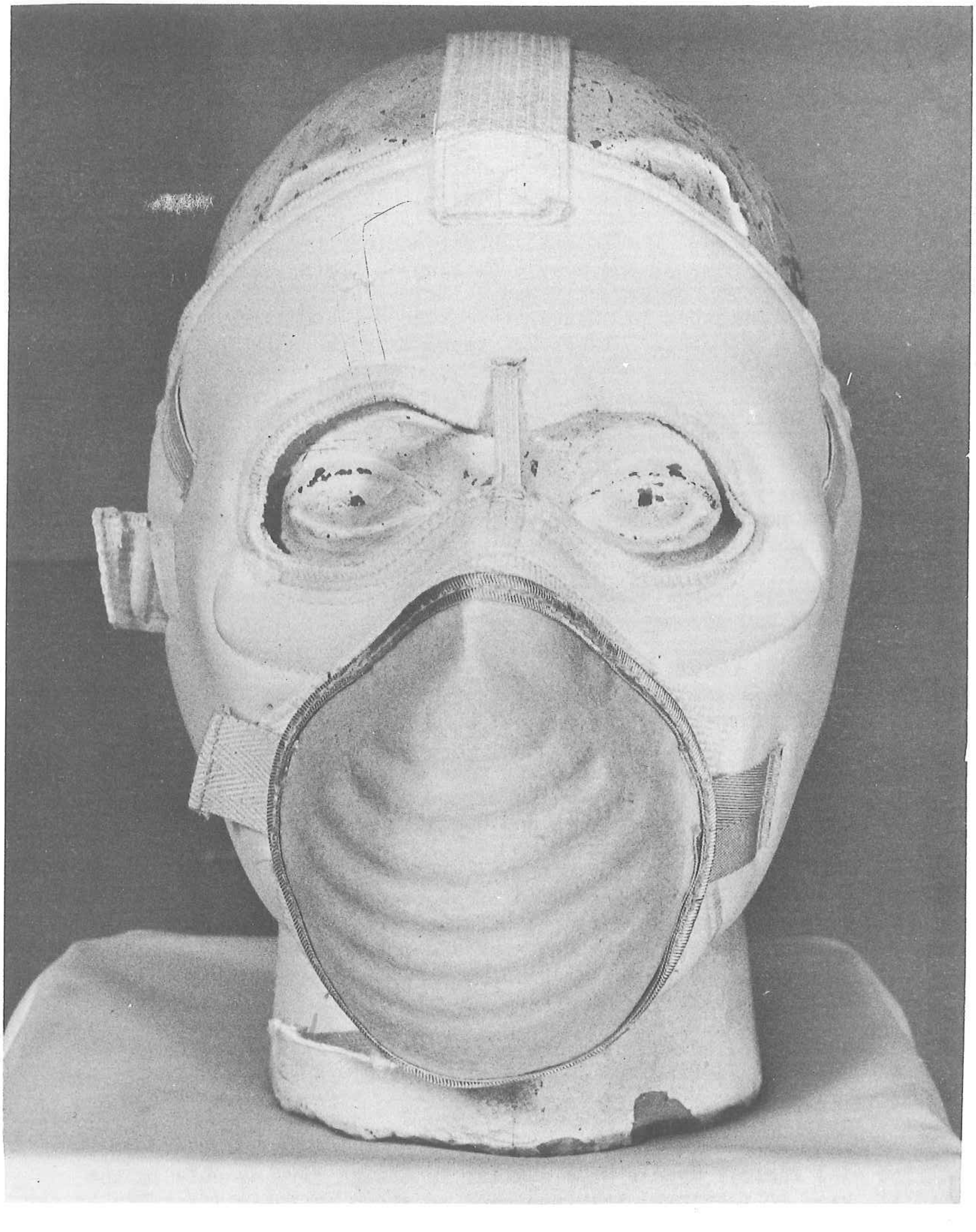


Figure 19. Phase I Prototype Mask

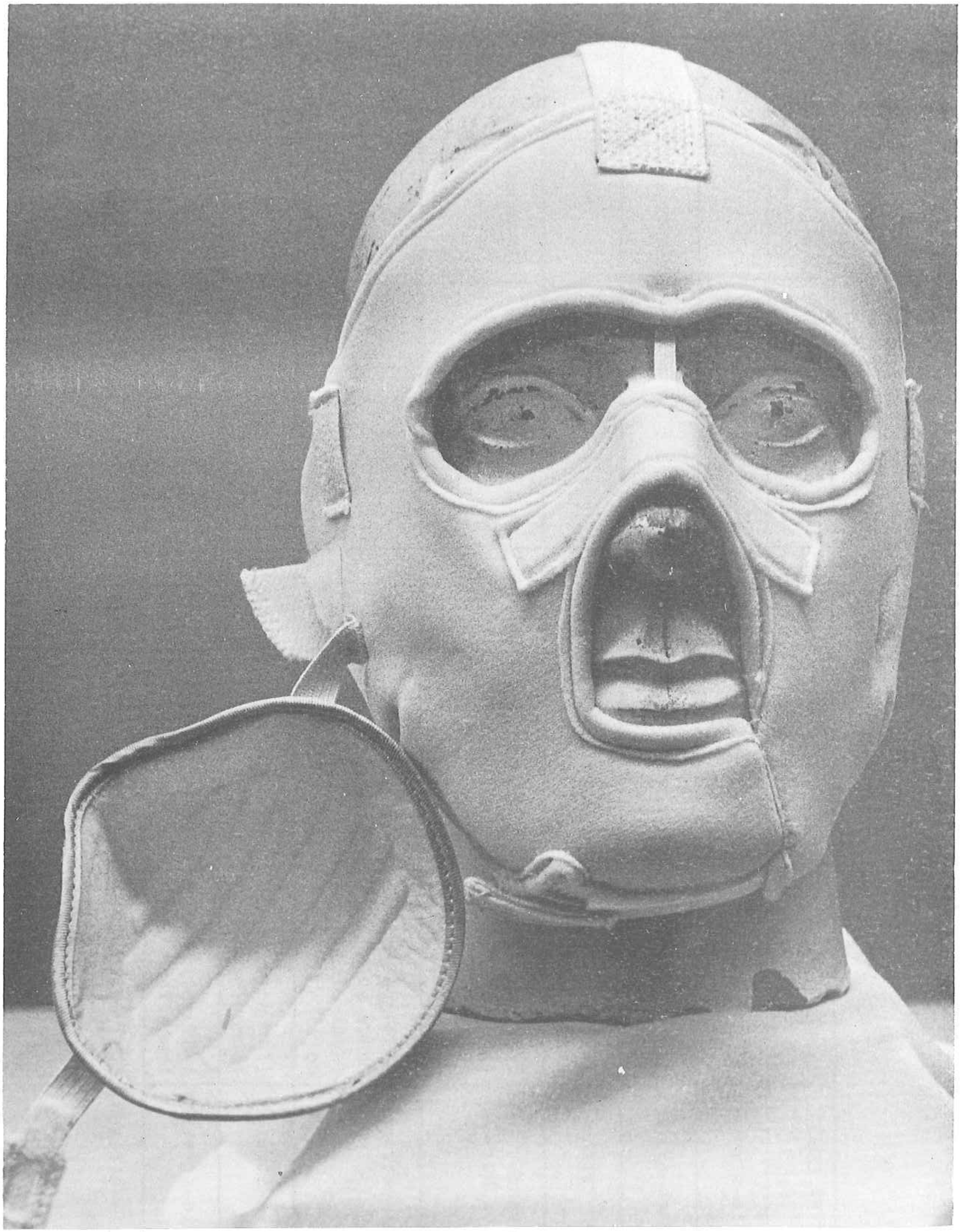


Figure 20. Phase I Prototype Mask Showing Oronasal Barrier in Open Position

TABLE VII

PHASE I PROTOTYPE MODELS

MASK #	OUTER COVER	INSULATING FILLER	INNER LINER	WEIGHT (ozs)	THERMAL CONDUCTANCE (btu/hr-ft^2-^{o}F)	AIR PERMEABILITY (cfm/ft^2/½"wat)
1	double-stretch nylon	3/8" polyester felt 4 oz/lin. yd.	cotton jer-sey	2.45	1.0	117
2	stretch-nylon	1/4" neoprene foam	cotton jer-sey	4.55	1.6	impermeable
3	nylon trichot	1/16" polyure-thane foam	cotton jer-sey	1.68	4.0	66
4	neoprene-coated hel-enca	1/8" polyure-thane foam	neoprene-coated hel-enca under knitted nylon	4.27	2.0	impermeable
5	double-stretch nylon	7/32" polyure-thane foam (semi-closed cell)	knitted nylon	2.66	1.2	107
6	double-stretch nylon	1/4" polyure-thane foam	cotton jer-sey	2.48	1.2	80
7	double-stretch nylon	1/8" polyure-thane foam	knitted nylon	2.56	2.0	116
8	double-stretch nylon	7/32" polyure-thane foam (semi-closed cell)	cotton jer-sey	2.45	1.2	84
9	double-stretch nylon	1/8" polyure-thane foam	cotton jer sey	2.35	2.0	89

its reported ability to wick away moisture without becoming wet. This latter material is a knitted 100% nylon.

The major difference among the nine models was the insulating layer. Polyester felt, neoprene foam, and various thicknesses of both open-cell and semi-closed cell polyurethane foam were used in an attempt to find the combination which would yield adequate protection and high wearer acceptance.

PROTOTYPE EVALUATIONS

The Phase I prototype masks were evaluated at Synsis and at the U.S. Army Natick Laboratories to identify deficiencies and to select two of the nine models for further development during Phase II. Synsis evaluations were concerned with sizing, fit, subjective acceptability, and compatibility with equipment and operations. Physical measurements of the masks' ability to protect and assessment of performance in cold environments were accomplished at Natick Laboratories.

SYNSIS EVALUATION RESULTS

The prototypes were fitted to a small and large headform and to a small number of subjects. The subjects also donned eyeglasses, goggles, the insulating cap, the field helmet and the parka hood. The masks were donned, doffed, fitted and operated while wearing Arctic mittens with knit wool liners. A sample of the mask was machine-washed, and machine-dried. The following observations and recommendations resulted from the evaluation:

1. The impermeable masks (# 2 and # 4) were stiff, bulky and subjectively objectionable to wear. The deficiencies were related to the particular materials used and not to the fact that they were impermeable.

2. The configuration was compatible with all of the clothing and equipment investigated. There were no interferences and the mask could be donned, doffed, and operated by the subjects without assistance and without difficulty.

3. The pattern used for the prototypes was generally adequate but needed to be adjusted to allow for differences in the way the various materials "made up"; some of the models were found to be undersize.

4. Minor modifications were indicated to: a) increase the area of coverage over the ears, b) increase the access to the oronasal area, c) increase the range of adjustment for the chin pocket, d) improve the attachment of the oronasal barrier and the head harness, and e) reduce the bulk of the mask seams to eliminate pressure points on the wearer's face.

5. Elastic strap and sewing thread needed to be selected which was compatible with laundering. Mask lost shape during machine washing and drying. However, the mask

survived hand washing satisfactorily.

NATICK EVALUATION RESULTS

Evaluations at Natick Laboratories included measurement of insulation values, investigation of the low-temperature properties of the mask materials and limited tests using human subjects exposed to low environmental temperatures. Insulation values were measured using a copper manikin head form and the results of these tests showed the prototype masks to provide significantly more insulation to the head than did the standard U.S. Army cold weather face mask. The relationship held at wind speeds of 10 and 30 mph and when the masks were worn alone or with the headwear items of the standard Arctic uniform. Prototype masks # 1 and # 6 appeared from the test results to give the highest insulation values.

Low temperature properties were assessed after cold-soaking the masks at -65°F. The masks containing neoprene (masks # 2 and # 4) were found to stiffen considerably at low temperature, but the mechanical characteristics of the remaining masks were not perceptibly changed. The cold-soaked materials could also be placed in contact with the face without subjective distress though somewhat more chilling was caused by masks # 2 and # 4.

Temperatures during the human subject tests in the environmental chamber ranged down to -40°F. A number of tasks were performed during these exposures ranging from a simple "walk-in" to performing simulated maintenance tasks. In general, the masks performed well; keeping the wearer warm and adequately protected. However, a number of problems were encountered. One of these problems was vertical oronasal mask movement. The oronasal mask was not adequately fastened to the facepiece and tended to shift around.

There were some fogging problems with the goggles and eyeglasses. This was due either to exhaled air entering the visual port from inside the mask or to warm, moist air rising from the outside of the oronasal mask and coming into contact with the eyeglasses.

Some accumulation of moisture in the permeable masks was also noted. At the end of one run, the mask was quite damp. This did not seem to interfere with adequate protection being afforded throughout the run.

Section VI

DETAIL DESIGN AND FABRICATION

As a result of evaluations performed on the Phase I prototypes and discussions held at the U.S. Army Natick Laboratories, a number of changes were identified for incorporation into the Phase II prototypes. The changes fell into the general categories of 1) improved fabrication techniques, 2) improvements in the area of coverage 3) improved fit, 4) improved attachment and mounting provisions, and 5) selection of materials covered by existing Military Specifications.

IMPROVED FABRICATION

It was noted during evaluation of the Phase I prototypes, that the mask seams were sufficiently bulky to cause some wearer discomfort. The use of a seam binding tape to cover the exposed edges of the facepiece laminate was identified as a complex and expensive approach for production.

Seam bulk was considerably reduced on the Phase II masks through use of a butt seam closed with a zig-zag type stitch (Seam Type FSa-1, Stitch Type 304 per Fed. Std. No. 751a) (3). The seams were reinforced at the ends with bar tacks to prevent raveling.

An overlock safety stitch (Seam Type SSa-2, Stitch Type 516 per Fed. Std No. 751a) (3) was substituted for the tape-bound edges used on the Phase I prototypes. The overlock stitch did provide all of the functions of the edge binding, but its physical properties were sufficiently different to require extensive redevelopment of the mask facepiece patterns to achieve an adequate fit. Other pattern modifications were required to eliminate sharp corners and small radii; considerable difficulty was experienced in attempting to follow sharp contours while applying the safety stitch.

AREA OF COVERAGE

The primary modifications to the area of coverage of the facepiece occurred in the oronasal region, and over the ears. The configuration of the oronasal opening was changed to provide improved access and to allow the change to the overlock stitch. The width of the facepiece tabs extending over the ears was changed to provide ear coverage for the range of head dimensions. These tabs were also rounded (see Figure 3) compared to those on the Phase I prototypes to accommodate the new edge finishing technique.

FIT IMPROVEMENTS

As noted above, considerable modification of the patterns was required to compensate for the alteration in edge finishing. In addition, however, it was necessary to improve the fit of the facepiece over the nose and to modify the chin pocket for a greater range of adjustment. Fit over the bridge of the nose was improved through use of a longer, heavier-gage malleable stiffener and internal padding in this region. The stiffener was contoured in the flat pattern to follow the lower edge of the visual port and

extended laterally to the extremes of the port (see Figure 4). Padding was added to the inner surface of the new stiffener and it was relocated on the inner surface of the facepiece (Figure 6). The new stiffener was fabricated of 0.025 inch aluminum conforming to Type 1100, Federal Specification QQ-A-250/1.

Increased face length adjustment was accomplished by deepening the notches at either side of the center flap to permit the facepiece to be made smaller than previously. Since the requirement had been for increased accommodation of large head sizes, the overall facepiece was then made sufficiently long that the minimum adjustment of the chin pocket would accommodate the small headform.

ATTACHMENTS AND MOUNTING

It appeared during the evaluation of Phase I prototypes that improvements could be made in several of the attachments and mounting provisions incorporated into the mask. The oronasal barrier was easily displaced from its correct position through interaction with head movements and with other items of clothing. The top strap of the retention harness tended to fall off center on many of the subjects who tried the mask and needed to be relocated in its attachment to the rear strap. Several modifications were called for in the provisions for integrating eyeglasses with the facepiece to simplify their donning and doffing. A minor change was indicated in the application of the hook and pile fastener used throughout the mask.

ORONASAL BARRIER ATTACHMENT

The oronasal barrier was originally attached by means of its own elastic straps (Figure 19) and hook and pile fastener tape. When subjects engaged in activity requiring considerable head movement while wearing the mask and the Arctic clothing assembly, the oronasal barrier was frequently displaced by contact with other clothing items. Several solutions to this problem were investigated all of which involved the subsitution of non-elastic straps and the more extensive use of hook and pile fastener.

The solution incorporated in the Phase II prototypes uses a short, inelastic strap to connect the barrier permanently to the facepiece and strips of hook and pile tape which extend around approximately three quarters of the barrier's periphery. The strap is sufficiently long that, when the barrier is detached, it hangs out of the wearer's way at the left side of his face. (See Figure 4). Since the strap is stretched taut by pulling on the tab at the right side of the barrier, the mask can be swung directly into contact with the facepiece with little or no misalignment.

Due to increased mating area for the hook and pile tape, the oronasal barrier is held quite firmly against the facepiece. The barrier can withstand relatively large forces due to wind or mechanical interactions without being displaced.

RETENTION HARNESS

The lateral location of the attachment between the top and back straps

of the retention harness was established by trial and error and was checked against anthropometric data. The final position of the attachment was not greatly different than that originally established, but the change appeared to have been functionally significant.

EYEGLASS RETENTION

The Phase I prototypes had elastic straps attached to the facepiece at either side approximately over the ears. In addition, the eyeglass frames could be inserted between the nosebridge elastic and the bridge of the nose and the stems inserted into the loops formed by the elastic straps over the ears. It was noted that it was somewhat difficult to insert the eyeglass frames behind the nosebridge elastic and that once the frames were positioned it was difficult to insert the stems into the loops over the ears. Due to the fixed position of the loops, the eyeglass stems and, thus, the lenses were tilted relative to their normal angle on some wearers.

In an attempt to alleviate the eyeglass mounting problem, the nose-bridge elastic was considerably lengthened to provide more stretch and the upper end attached to the outside of the mask to prevent the mask being pulled away from the face by the glasses frames. The upper edge of the visual port was modified slightly to compensate for the loss of covered area due to lengthening the elastic.

The elastic loops at the sides of the facepiece were lengthened slightly and reoriented to lie in a better position for inserting eyeglass stems. Half of the Phase II prototypes were supplied without loops so that the facepiece could be slit in the region over the ears. The slits were to be edged with a buttonhole stitch and the eyeglass stems would be inserted through the slits to rest directly on the wearer's ears.

HOOK AND PILE FASTENER

The Phase I prototypes were arbitrarily designed to have the pile portion of the hook and pile fastener attached to the facepiece. During evaluation of those prototypes it was noted that the hook tape had an affinity for the stretch nylon outer covering of the facepiece laminate to the extent that it frequently became firmly and inconveniently attached to the covering. The application of the fastener tape was revised for the Phase II prototype so that all hook tape was stitched onto the facepiece facing outward and only the pile tape faced inward towards the laminate. This change completely eliminated the previously noted problem.

MATERIAL SPECIFICATIONS

In order to facilitate type classification of the cold weather face mask design, an effort was made to use materials covered by existing Military/Federal Specifications in the fabrication of Phase II prototypes. The following materials were selected for incorporation into the prototypes as a result of discussions held with the Contract Monitor:

1. Stretch Nylon Outer Cover - Class 2 of MIL-C-43247A (16) except white in color.

2. Retention Harness - Type I, Class 9, 1¼" wide of JJ-W-155E (17) with exceptions noted in paragraph 3.3.4 of MIL-D-40099 (18).

3. Eyeglass Holder - Type II, Class 3, 1/2" wide of JJ-W-155E.

4. Nose Bridge Elastic - Type II, Class 1, 5/16" wide of JJ-W-155E.

5. Hook and Pile Fastener Tape - per MIL-F-21840C, Type determined by width and application (19).

6. Thread - Polyester/Cotton wrapped, Ticket No. 70, 2 ply, unbleached of MIL-T-43548(4).

7. Nose Bridge Stiffener - Type 1100, Federal Specification QQ-A-250-1.

Section VII

CONCLUSIONS AND RECOMMENDATIONS

This program resulted in the fabrication of prototype models of an improved cold weather protective mask suitable for laboratory and field testing. These models embodied design concepts, formulated by a combination of analytic studies and design evaluations, intended to fulfill both operational and performance requirements. Based on the analytical evaluations and limited testing conducted during the program, certain conclusions and recommendations were developed and are presented in this section.

THERMAL PROTECTION

The prototype masks will provide individual protection against windchill for all environmental conditions to -65°F and wind velocities to 35 mph. Complete enclosure of the face coupled with the use of appropriate components of the standard Arctic headgear assembly will ensure freedom from frostbite over extended time periods. In the prototype design, facial coverage by the mask has been extended to encompass the wearer's ears and to increase the area of overlap between the mask and the insulating cap, over that provided by the current standard protective mask. In addition to this 20% increase in head coverage, the prototype incorporates an oronasal barrier which completely encloses the mouth and nose and provides a respiratory "dead-space". This reduces the magnitude of oronasal heat loss and precludes the inhalation of air at the environmental extreme.

DONNING EASE

Through incorporation of fitting adjustments, elastic materials and the use of hook and pile attachment points, donning of the protective mask can be easily accomplished. A recommended procedure for donning and adjusting the mask is presented in the Appendix. The mask provides a means for preadjustment to the wearer which enables donning with a single point attachment. This donning procedure can be accomplished rapidly and effectively without assistance while wearing the Arctic mittens.

With the preadjustment technique the mask cannot be donned incorrectly. The mask is self indexing to the face through the use of a chin pocket.

SIZING AND FIT

The prototype mask will adequately fit the military population with a single-sized device. This is made possible by use of the chin pocket adjustment which compensates for the large range of face lengths. Use of compliant materials in the face piece and in the restraint harness permits form fitting to the face.

Padding material incorporated in the nose bridge area of the facepiece plus the use of a formable metal strip will permit compliance of the mask to the wearer's face. This concept results in the form fitting of a seal to separate the oronasal compartment from the visual compartment thus tending

to minimize fogging of the inside lens surface of the goggles.

COMFORT AND ACCEPTABILITY

Wear trials of the prototype mask with subjects varying in facial structure, typically demonstrated greater comfort and ease of donning than did the standard cold weather protective mask. The relative non-occlusion of the visual field, absence of pressure points, and facepiece and harness compliance with facial movements, increase the level of wearer acceptance over other contemporary protective masks.

A major problem with cold weather protective masks is the accumulation of moisture internally. The prototype mask minimizes this problem by the use of permeable facepiece materials. The wicking action prevents the accumulation of moisture due to insensible perspiration.

The compliance of the mask materials and the retention configuration result in mask stability on the face during wear. The mask will cling to the face and due to the chin pocket configuration does not slip even when the wearer performs jumping maneuvers or moves his head rapidly.

CLOTHING/EQUIPMENT COMPTABILITY

The prototype mask has been specifically designed for compatibility with the Arctic protective headgear assembly. No interference with any component of this assembly is evidenced. Additionally the mask will permit the simultaneous wear of either goggles or eyeglasses without impeding the performance of either item. Because of its low bulk in the visual area, the protective mask should not interfere with the use of any other item of optical equipment.

In the use of communication equipment the oronasal access feature of the mask will permit excellent performance of communication tasks without necessitating removal of the mask. In addition, the oronasal barrier will permit speech transmission under most typical military environment noise conditions.

STORAGE COMPATIBILITY

The protective mask will remain compliant and will withstand flexure without cracking at all storage temperatures to -65°F. The mask can be stored in a folded condition without assuming a fixed set which will impede its performance.

ELECTROSTATIC COMPATIBILITY

While extensive material testing was not accomplished, the materials incorporated into the cold weather mask do not create an obvious problem with build-up of static charges, and they all represent materials which are presently incorporated elsewhere in cold weather clothing.

PRODUCIBILITY

In large production quantities the protective mask can probably be produced at an economically feasible cost. Production does not require expensive tooling or other special facilities. Conventional stitching is used throughout the mask and the materials employed are currently produced in large quantities and are readily available.

RECOMMENDATIONS

Although the analyses and evaluations performed on the prototype mask have established acceptability of the design several additional investigations are recommended. Included in these recommendations are several which are intended to optimize the total protection system.

TEST AND EVALUATION

Since test and evaluation during the current program have been limited in the number of test subjects and conditions included it is suggested that confirmatory studies be performed under both laboratory and field condition. The objective of this testing should be the assessment of suitability for universal application within the military environment and operations. Results of the testing can be used as guidance for design optimization and as a basis for determining the potential cost-effectiveness of a large production program.

COMMUNICATIONS ENHANCEMENT

Wearing the prototype mask, together with the standard Arctic headgear, results in potentially four layers of clothing over the ears. As a consequence a certain amount of hearing decrement will result. It is therefore recommended that the extent and consequence of this hearing decrement be determined and techniques and approaches be studied to increase sound transmission without degrading thermal protection to an unacceptable level. This should include investigation of alternate insulating materials, providing acoustic "short-circuit" paths, and alternate thermal protection design concepts.

IMPROVED INTEGRATED HEADGEAR ASSEMBLY

Although the prototype protective mask achieves low bulk and preserves the wearer's visual field, penalties are encountered when the total Arctic headgear assembly is donned due to the bulk of the hood of the parka. The current investigation should be expanded to determine if a total head protective device could eliminate the need for the hood. As an alternative approach, increased coverage of the protective mask can be used to replace the function of the insulating cap.

Section VIII

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APPENDIX

RECOMMENDED

DONNING AND ADJUSTMENT INSTRUCTIONS
COLD WEATHER FACE MASK

Donning of the cold weather face mask is accomplished without assistance and may be performed when wearing protective gloves and mittens. It is recommended that the mask be adjusted for wearer face length during the initial donning operation; readjustment of the chin pocket should not be required during subsequent donning operations.

DONNING PROCEDURE

Proper fitting of the face mask requires that it be properly centered on the face with the chin placed firmly in the chin pocket and the eyeport positioned over the eyes to preclude visual interference. Donning of the mask for the first time will be considerably facilitated if a mirror is available. The following steps are to be performed sequentially to ensure effective donning:

1. Check the condition of the chin pocket. If it is open form the pocket by bending the center tab inward and then fastening the side tabs by overlaying the hook and pile fastener.

2. Detach the oronasal barrier from the facepiece by pulling on the barrier tab.

3. Place the mask on the face by inserting the chin into the chin pocket and aligning the eyeport over the eyes. When properly oriented the eyeport should not obstruct vision and the oronasal port should provide clearance for the mouth and tip of the nose (A).

4. If the chin pocket prevents eye and oronasal alignment it is to be disengaged and refastened to provide greater slack.

5. Holding the mask in place with the one hand, grasp the attachment harness back strap tab with the other hand, pull the back strap around the back of the head, and attach the hook and pile fastener at the right side of the facepiece (B).

6. Center the top attachment strap over the crown of the head (C).

7. Readjust the mask to ensure comfort and proper alignment of the eye and oronasal ports. The chin pocket adjuster can be used to position these ports in the vertical direction. Tightening the adjuster (separate the fastener, pull ends

Donning and Adjustment Procedures

closer and reconnect) tends to pull the mask down on the face. Conversely, loosening the adjuster will permit the mask to move on the face (D).

The chin pocket adjuster can also be used to loosen or tighten the mask in and around the jaw area. The adjuster should be tightened until the mask feels snug, but not uncomfortable. The mask should not shift position during head or jaw movement.

8. To properly seal the mask on the face mold the stiffener bar to the contours of the face by applying finger pressure. The stiffener bar is located over the bridge of the nose and extends laterally under the eye port. Molding of the stiffener bar can best be accomplished by pressing down and inward on the bar starting at the nose bridge and moving outward as required. Care is to be exercised in this operation to avoid excessive pressure on the nose and face (E).

9. Closure of the oronasal port is accomplished by pulling the oronasal barrier over the port and fastening in place with the hook and pile fastener (F).

10. To remove the mask, simply disengage the attachment backstrap fastener. By leaving the chin pocket adjuster firmly engaged subsequent donning of the mask will be simplified.

Mask wearers who require the use of corrective eyeglasses or desire to wear sunglasses can install these by one of three methods:

1. After donning the mask the eyeglass stems are inserted in the eyeglass holders on the sides of the mask above the ears. This method may tend to hold the frames slightly forward of the normal wear position.

2. Install the eyeglasses prior to donning the mask so that the eyeport center elastic strap is outboard of the frames and the stems are inserted through the eyeglass holders.

3. After donning the mask, insert one stem under the eyeport center elastic strap. Pull the frames into wearing position by rotation of the frames and insert the stems through the eyeglass holders.

The donning of protective goggles is accomplished by typical procedure after the protective mask has been donned.

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Synsis, Inc. Los Angeles, California	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

Prototype Cold Weather Face Mask

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Research

5. AUTHOR(S) (First name, middle initial, last name)

David Mangelsdorf, Samuel Tobey, Richard Colman and Marvin Goldberg

6. REPORT DATE February 1971	7a. TOTAL NO. OF PAGES 72	7b. NO. OF REFS 19
8a. CONTRACT OR GRANT NO. DAAG17-70-C-0113 b. PROJECT NO. 1J664713D547 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) 71-45-CE (C&PLSEL-85) 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY U. S. Army Natick Laboratories Natick, Massachusetts

13. ABSTRACT

An improved cold weather face mask has been developed which should provide protection from cold, wind, blowing snow, and frostbite in environments to -65°F and 35 mph wind velocities. The mask provides physical compatibility with military clothing and equipment and will not occlude the field of vision. It weighs less than 2 1/2 ounces, covers the forehead, cheeks, nose, ears, chin and mouth, and is designed such that a single-size mask can adequately accommodate the U. S. Army population. Provisions are included to permit eating, smoking, relief of excess moisture accumulations, and elimination of oral and nasal body wastes. The mask is composed of a laminated insulating material facepiece, an oronasal thermal control barrier and an adjustable retention harness. The laminated material consists of a stretch nylon outer layer, a cotton jersey inner layer and an insulating interlayer. In the final configuration, mask models were produced using either a 1/4-inch polyurethane foam or a 3/8-inch polyester felt for the insulating interlayer. The laminated material has sufficient compliance and stretch to conform well to a wide range of facial contours.

The development process involved a nine-month, two-phase, system-oriented design study. The first phase included a design requirements analysis, and a configuration synthesis task. The analyses provided basic thermodynamic psychophysiological, and compatibility criteria for the selection of candidate materials, configuration concepts, and system designs. The basic design concepts were analyzed and promising candidates selected, fabricated, and subjected to a preliminary evaluation. As a

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DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

Unclassified
Security Classification

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Design	8					
Development	8					
Face masks	9					
Protection	4					
Wind chill	4					
Face (Anatomy)	4					

Unclassified

Security Classification

13. ABSTRACT (Cont'd)

result of the preliminary evaluations, designs for a final prototype mask were selected for further development.

During Phase II certain design modifications, deemed desirable as a result of the preliminary evaluation, were made to the selected design approaches. Quantities of the prototypes were then fabricated and delivered to the U.S. Army Natick Laboratories.

From the preliminary evaluation, it was generally concluded that the area of facial coverage provided by the mask is satisfactory and that the mask, when combined with other elements of Arctic clothing, offers excellent protection against severe windchill.

Although the prototype mask provides acceptable auditory reception, severe attenuation was observed when the complete Arctic clothing ensemble is worn. It is thus recommended that techniques to improve audio-transmission through Arctic headwear be developed.